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A synoptic case study of objective tropical analysis.

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THESIS

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OF
OBJECTIVE TROPICAL ANALYSIS

by

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of
Objective Tropical Analysis

by

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ABSTRACT

The author presents an evaluative study of Fleet Numerical Weather Central's 0000 GMT surface and 250-mb wind analyses in the Pacific Ocean area 40N to 40S, 120E to North and South America, for the period 8 - 22 March 1972. The evaluation considers the suitability of the variational analysis scheme and data base by relating numerically- and subjectively-analyzed versions of the two levels for each synoptic time. The report includes an extensive sample of such charts. Several climatologies, including one based on the most recent one or two weeks of analyzed data, were considered along with persistence for the purpose of generating an optimum 24-hour first-guess wind field for analysis or prognosis.

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I. INTRODUCTION

This thesis investigation represents an evaluative study of a fourteen-day period (8-22 March 1972) of the United States Navy Fleet Numerical Weather Central's (FNWC) Global Band Analysis (GBA). Two levels were selected for study, namely the surface and 250 mb. Both numerical and subjective analyses were produced by the author, for the purpose of achieving the objectives outlined below.

The objectives of this investigation, utilizing the Fleet Numerical Weather Central's Global Band Analysis for tropical Northern and Southern Hemisphere areas, are three-fold: (1) to test the suitability of the numerical variational analysis (NVA) scheme, first presented by Sasaki (1958) and integrated into the FNWC analysis program by Lewis and Grayson (1972), to adequately depict the synoptic-scale features of the tropical atmosphere; (2) to demonstrate the enhancement of the tropical analysis at sea level and 250 mb through use of maximum data sources and minimal rejection of data; and (3) to test various schemes, at the 250-mb level, to increase the validity of the first-guess analysis and test its suitability as a 24-hour prognostic field.

II. BACKGROUND

During the past two decades many of the major meteorological centers throughout the world have developed automated analysis techniques for the tropics based essentially on Cressman's (1959) method of successive corrections to a first-guess field. In recent years, Bedient and others (1967) at the National Meteorological Center, National Oceanographic and Atmospheric Administration, (NOAA), have developed an advanced program of tropical analysis based on extensive use of satellite-derived information.

More recently, Grayson (1971) and Lewis and Grayson (1972), have developed a program for operationally producing an analysis of surface wind and sea-level pressure at FNWC every six hours. The analysis is generated on a global band (hence the name Global Band Analysis) extending from 60N to 40S, on a Mercator projection true at 22.5 degrees, with a grid length of 2.5 degrees of latitude. This provides a data interval of approximately 150 nmi at the equator and 75 nmi at 60N. Lewis and Grayson were able to incorporate wind reports into the pressure analysis scheme proposed and modified by Sasaki (1969). Lewis (1972) has extended the FNWC GBA into the upper atmosphere (250 mb) through the vertical coupling of temperature and wind from the data-dense surface to jet-aircraft levels.

This study is concerned with an evaluation of the FNWC GBA model as of March in 1972, as well as with the

potential improvement of the analysis by incorporating as many data as possible from all sources, thereby providing a "best" starting point for tropical prognostic models. Lewis and Grayson (1972) have demonstrated that the utilization of NVA does provide an improved analysis in data-sparse areas, and it must follow that increasing the data input will improve the analysis.

Given maximum data input, it remained to be determined just how to provide a best first guess to the analysis. One of the most widely applicable and purely objective techniques is a method developed by Lavoie and Wiederanders (1960) to forecast upper winds in the tropics. This method uses various combinations of persistence and climatology to forecast upper-level winds at specific points. Weighted means were determined and applied as coefficients of persistence and climatology to produce a first guess which, in their case, was a 24-hour forecast. It was demonstrated that weighted means produced the optimum 24-hour forecast, but a 50-50 combination of persistence and climatology (Figure 1) yielded equal results. This approach is ideally suited for utilization of the computer to produce an optimum combination of persistence and climatology to use as a first-guess field in the automated wind analysis.

An investigation of the influence of different climatologies in producing a first-guess field was also carried out. Initially, the author developed a short-term (also

called current) climatology based on the 14 days of analyses (8-22 March 1972) in the Pacific Ocean. This climatology was then combined with persistence in various proportions, and the result compared with similar combinations of persistence and other climatologies. These are the climatologies of (a) FNWC (Figure 2) developed by the National Center for Atmospheric Research (NCAR), Boulder, Colorado, utilizing rawinsonde data from the National Weather Records Center, (NWRC) through 1964; (b) that developed by Sadler (1970) (Figure 3) utilizing aircraft reports from 30S to 50N and east of 155E to 90W for the period 1960-1968; and (c) that climatology used by FWC Pearl Harbor (Figure 4) which is based on rawinsonde data from 1957-1964 covering essentially the same area as Sadler's climatology. These aforementioned climatologies, as noted in Figures 2-4, are for the 250-mb level in the Pacific Ocean with the areas in Figures 3 and 4 smaller than the area in Figure 2.

Presently at FNWC, the GBA is produced every six hours. In the belt between 20N and 60N the first-guess to the analysis is either the six- or 12-hour forecast from the FNWC primitive equation model. Elsewhere, south of 20N, the previous analysis (i.e., persistence) is used, as there is no forecast model available for the tropics or the Southern Hemisphere.

III. DATA SOURCES

To become thoroughly familiar with the FNWC global band analysis, the author manually analyzed a selected series of charts in January and February of 1972, utilizing the same data used in the GBA. These analyses were accomplished in response to a request by Dr. Lewis, FNWC, as a check on the time and space continuity of the NVA scheme utilized in GBA.

It was immediately apparent in all the analyses that where the available data were plentiful, the NVA scheme portrayed an accurate depiction of the synoptic features in existence at the time. Because of the complete objectivity of the scheme, features such as troughs in data-dense areas were very accurately placed.

Where data were sparse or simply non-existent, as over large areas of the Southern Hemisphere, the wind analysis program yields an approximate 20% return toward climatology per day. Thus, after about five days of no data, the analysis becomes a replica of the climatology base. Additionally, available reports are scanned systematically, using the successive corrections method (SCM) of the NVA with various weighting functions applied to the data. As a result of this scanning process in the NVA program, many seemingly valid wind observations are rejected due to the limitations on speed or direction or both. This also results in a smoothing process in areas of little or no data.

For example, when a system, such as a cyclone, moves into an area of no data, the cyclone weakens or is analyzed as a trough, which is a reflection of the smoothing mentioned above and the influence of the climatology in the NVA program. However, any systems moving into an area of dense reports would be analyzed correctly. Similar analysis features are discussed in the Appendix. In general it is the opinion of this author that the NVA scheme accurately portrays the synoptic situation in data-dense areas, and adequately in data-sparse areas.

Once the necessary familiarity and confidence in the analyzing scheme was attained, the period of 8-22 March 1972 was selected for study. A mid-month period was chosen so as to closely bracket the representative dates of monthly climatological charts. The synoptic time selected was 0000 GMT and the area chosen was the Pacific Ocean, from 40N to 40S and east of 120E to the coasts of North and South America. The 0000 GMT time was used because of the availability of data in the Pacific at this hour, particularly ship observations and ATS photographs during daylight hours. The area was selected because of the mix of data-dense and data-sparse areas, the large size of the area, the available climatologies and the large expanse of coverage from the ATS I satellite data.

The data were a combination of those available to the GBA program in real time and the following additional

sources which are potentially available for operational use: subjective satellite interpretations, ATS cloud-vector motions, Satellite Infrared Spectrometer (SIRS) data, coded analyses from the Southern Hemisphere (canned data) and late data. A brief description of these data follow.

A. SUBJECTIVE CHANGES TO THE ANALYSIS DUE TO INTERPRETATION OF WEATHER-SATELLITE OBSERVATIONS

Since the initial operational ESSA weather satellites began orbiting the earth in 1966, routine operational use of satellite cloud pictures have steadily increased. Not only does satellite interpretation provide data in sparse data areas, but it also provides additional clarity and understanding over areas where the conventional observations are dense. ATS I and III photographs were analyzed utilizing the methods of Anderson et al (1966) and Anderson (1969), which provided the rules for the interpretation of the cloud pictures to guide in the repositioning or location of circulations not apparent in the conventional or other data used in this study.

B. CLOUD-VECTOR WINDS

Cloud-vector motions interpreted from the ATS satellite photography were employed as a data source. Prior studies, Simpson and Gaby (1970), Hubert and Whitney (1971) and Gruber et al (1971), indicate the feasibility of utilizing motions from low-level clouds as representative of 2000-foot winds and from high-level clouds as substitutes for

300-mb or 200-mb winds. These winds are derived from time-lapse photographs produced by the National Environmental Satellite Service (NESS) personnel on a routine basis and are available to FNWC on their normal computer circuits. These winds were plotted on charts of the nearest corresponding level and used in areas where data were sparse and as a check for data which may have been rejected by the computer.

C. SATELLITE INFRARED SPECTROMETER (SIRS) PRESSURE-TEMPERATURE DATA

SIRS data have been available (irregularly) to meteorologists since the third NIMBUS satellite was launched. Since 1969, these data have been processed on a daily basis at NESS and utilized by the National Meteorological Center (NMC) in the Northern Hemisphere analysis for both 0000 and 1200 GMT. Hayden (1971) compared tropospheric height and thickness values derived from NIMBUS 3 SIRS data with nearby radiosonde data to determine a) the accuracy and compatibility of the SIRS data, and b) the utility of SIRS data for objective analysis. Hayden found that SIRS thickness values at high levels have the same accuracy as radiosonde measurements. Smith (1969) and Endlich et al (1971) show further utilization of SIRS data as an addition to conventional data.

In order to produce a SIRS sounding there must be a forecast provided at the 850-mb level which is used as the

reference level. Because routine forecasts are presently available only in the Northern Hemisphere, there were no SIRS data available elsewhere. Also, because of a malfunction, the data were not complete for the entire hemisphere during the period 8 - 22 March 1972. Wind gradients were derived from the available SIRS data and used as an aid in the subjective analysis when possible.

D. CANNED MAPS (IAC FLEET)

The canned maps are an analysis of surface or upper-air charts in the International Analysis Code form used by the World Meteorological Organization. The surface analyses from the Southern Hemisphere were obtained from FNWC and utilized to aid in the location of pressure systems, fronts and tropical cyclones.

E. LATE DATA

Late data are construed as those arriving after data cut-off time, which at the time of this study was four hours after observation time(i.e., 0 + 4 hours), but before ten hours after observation time, (i.e., 0 + 10 hours). The latter cut-off time represents the latest time for use on a final "0" time analysis. Data arriving after 0 + 10 hours are not kept on file or stored. In an attempt to determine how many data arrived between 0 + 4 and 0 + 10 hours, printouts of selected days' data were obtained from FNWC and compared with data actually on the chart. It was

found that for the area in the study, south of 25N in the North and South Pacific Oceans, there were an additional 15 to 20 aircraft reports, about half of which were in the Southern Hemisphere. This is a considerable number when one considers the scarcity of reports in this region.

The additional data described above were plotted along with those available to the GBA; or, in the case of the satellite interpretation of video data, positions of centers, divergent/convergent flow and frontal systems were noted on the chart. The analysis was then completed on the plotted charts for the surface and 250-mb levels. These charts are illustrated and interpreted in the Appendix.

IV. COMPUTATIONAL PROCEDURES

Upon completion of the wind analyses at the surface and 250-mb levels, it was decided to test various objective schemes for producing a best 24-hour first-guess. The 250-mb level was selected for this purpose. The choice of this level was arbitrary, but it did show more daily variability than the surface chart.

A purely objective forecast technique removes the inherent subjectivity attributed to the experience of the meteorologist. Such a forecast can be arrived at independently by any forecaster. Lavoie and Wiederanders (1960) developed a method to forecast 30,000-foot tropical winds that has been applied widely because it is a purely objective technique. This method uses various combinations of climatology and persistence to forecast winds at specific grid points. Twenty-four hour lag correlation coefficients of persistence and climatology were computed for each grid point. These percentage combinations were then utilized to produce optimum accuracy for a 24-hour forecast using a linear regression approach. The 24-hour mean vector wind was computed for each day in May 1959 for climatology, persistence and a 50-50 combination of the two. It is apparent from Figure 1 that the 50-50 combination is consistently more accurate than either persistence or climatology. Lavoie and Wiederanders also suggested that in the absence

of long-term mean values, a running mean of the past 10 or 15 days (i.e., a short-period climatology) could be substituted. Another more recent attempt at developing a short-period climatology was made by Gaby and Poteat (1971), utilizing winds derived from cloud-vector motions in the North Atlantic Ocean area.

An approach similar to Lavoie and Wiederanders was utilized in this study. Once the best analysis was produced, it remained for the analysis to be reduced to grid-point values and subjected to various tests to produce a best 24-hour first-guess forecast.

Initially then, the short-period climatology was derived in the following manner: analyzed data for each day were read for each five-degree latitude/longitude intersection (Figure 5) and put on punch cards. One- to 14-day current climatologies were produced by decomposing the wind into its zonal and meridional components, summing and determining the means in the following manner:

$$CC_u = \sum U_{ob}/N \qquad (1)$$

$$CC_v = \sum V_{ob}/N \ , \qquad (2)$$

where CC_u and CC_v are the zonal and the meridional components of the current climatology, U_{ob} and V_{ob} are the components of the analyzed wind and N is the number of wind observations at each grid point. An example of the current climatology for a 14-day (N = 14) period is shown in Figure 6.

In computing a first-guess wind field, weighting coefficients on climatology and persistence were initially restricted to 75, 50 and 25%, but later expanded to include every 10% from 0 to 100% with the total weights always equaling 100%. A first-guess wind was then produced by the following formulae:

$$FG_u = (A)U_{ob} + (1-A)\ CC_u \qquad (3)$$

and

$$FG_v = (A)V_{ob} + (1-A)\ CC_v\ , \qquad (4)$$

where FG_u and FG_v are the first-guesses for the zonal and meridional components, respectively, and A is the weighting coefficient. In computing the first-guess (i.e., 24-hour forecast) wind, persistence is the current observation, while current climatology is developed from all the days available prior to the current day. Once the first-guess wind (Figure 7) has been derived from grid-point data, a vector difference between the first-guess wind and the verifying analyzed data is computed at each grid point (Figure 8). Finally, the root-mean square error (RMSE) of the vector difference is computed. These formulae are:

$$VD_u = U_{ob+1} - FG_u \qquad (5)$$

and

$$VD_v = V_{ob+1} - FG_v\ , \qquad (6)$$

where VD_u and VD_v are the zonal and meridional components of the vector difference defined above. U_{ob+1} and V_{ob+1} are the analyzed grid-point winds at the time for which the first-guess winds have been forecast. The RMSE's were

computed using:

$$RMSE = [(UU)^2 + (VV)^2]^{1/2} , \tag{7}$$

$$(UU)^2 = \sum (VD_u)^2/M , \tag{8}$$

and

$$(VV)^2 = \sum (VD_v)^2/M , \tag{9}$$

where UU is the zonal component and VV the meridional component of the RMSE, respectively, and M is the number of grid points.

The previous methods for testing were also applied to the vector differences resulting from use of the climatologies developed by Sadler, by FWC Pearl Harbor and by NCAR for FNWC.

An additional test was based on the following. It was felt that the optimum weighting coefficients of persistence and climatology, as given in Equations (3) and (4), were dependent on the magnitude of the wind steadiness (WS). The latter is defined as:

$$WS = \frac{\text{average vector wind}}{\text{average scalar wind}} \quad \text{or}$$

$$WS = \frac{(CC_u^{\,2} + CC_v^{\,2})^{1/2}}{\sum |V|/N} \tag{10}$$

where CC_u and CC_v are defined in Equations (1) and (2) and $|V|$ is the scalar wind speed value at each grid point. On the basis of part theoretical and part speculative reasoning, it was felt that the steadier the wind the greater the relative influence of climatology. Arbitrarily, the

following decision was taken: (a) when WS $\geq$ 70% (high steadiness) use a 25/75% ratio of persistence to climatology, (b) when 50% < WS < 70% (moderate steadiness) use a 50/50% ratio of persistence to climatology, and (c) when WS $\leq$ 50% (low steadiness) use a 75/25% ratio of persistence to climatology. The results of this test are encouraging and are discussed in the next section.

V. TESTING FOR AN OPTIMUM FIRST-GUESS ANALYSIS

The subjective analyses, completed after utilizing the additional data as noted in the Appendix,were deemed to be the most correct analyses for the area concerned. Because of the scale of map utilized for the GBA, namely 1: 40,000,000, it was decided that a five-degree latitude/ longitude grid would be used (Figure 5) to read wind values. After the current climatology was developed, it was then utilized in the manner discussed in the prior section to produce first-guess wind fields and the vector errors. These vector errors were then reduced to a Root Mean Square Error (RMSE) value for each 24-hour forecast. The different climatologies were also tested under the same process.

Table I shows the result obtained from computing the RMSE values for the different combinations of persistence and the several climatologies. Utilizing current climatology only, wind steadiness factors were then computed at each grid point, allowing the value of the wind steadiness to determine the percent of persistence and climatology used. Figures 10 and 11 are graphs of the data in Table I.

The 8-day RMSE was computed as follows. The 6-day current climatology was used in combination with the 7th day analysis to produce the 8th day first guess which is then compared to the 8th day wind. In a similar manner, a 12-day current climatology is used to produce the 14-day RMSE.

In the cases of the long-term climatologies (i.e., FNWC, Sadler and FWC Pearl Harbor), the climatology was used in combination with the respective 7th day and 13th day analyses to produce the 8- and 14-day RMSE's, the results of which were then compared with that using the current climatology.

Both the 8- and 14-day results show greatest RMSE when the percentage of persistence is highest. Improvement results as the percentage of climatology is increased, with the minimum RMSE occurring in all cases for a climatology weighting between 60 and 90%.

It is apparent from the 8-day chart (Figure 10) that the current climatology is definitely better to use as a basis for a first guess than the other climatologies. The best combination of persistence/climatology occurs at 20/80 for the current climatology, 40/60 for FNWC, and 30/70 for both Sadler and FWC, Pearl Harbor. A surprising result is that FNWC, with a data base dependent only on radiosonde data, proved to be slightly better than either of the other two long-term climatologies.

In the 14-day chart (Figure 11) the four climatologies are very close in RMSE with FNWC providing the best first-guess. Comparison of Figures 10 and 11 show an interesting result, namely the shift to the right of the best persistence/climatology combination for all cases but the current-climatology. It is to be noted that as the time period is

extended from 8 to 14 days, the long-term means provide a slightly better first-guess wind field.

The test of the steadiness-dependent current climatology yielded RMSE's of 29.7 kt and 29.3 kt for 8 and 14 days, respectively, which compares favorably with the optimum RMSE values in Figures 10 and 11. A further test, exactly reversing the values of the persistence/climatology combination, yielded RMSE's of 33.3 and 34.6 for 8- and 14-days, respectively.

A final test was conducted utilizing the FNWC and successive overlapping 6-day current climatologies. Beginning with the initial 6-day climatology (8-14 March), a first-guess wind field was produced for 16 March, then utilizing the adjacent but overlapping 6-day current climatology (9-15, 10-16, 11-17, March, etc.) the next succeeding six first-guess wind fields were produced (17, 18, 19, 20, 21, 22, March). The RMSE curves of these first-guess fields, along with their climatology and persistence weighting coefficients, are shown in Figures 12 and 13 similar to that in Figures 10 and 11. Curves numbered 1 in Figures 12 and 13 are the same as their corresponding FNWC and current-climatology curves in Figure 11. In this manner, comparisons were available, for each 8-day period of this study, between the RMSE values of the current and FNWC climatologies.

The results of this test cover too short a time period to be conclusive; however, the current climatology continues to provide a lower RMSE in the majority of cases and the behavior of the curves in the two cases is very similar. Evidently, the large jump in optimum weighting of persistence and climatology noted between the curves in Figure 12 indicate the necessity for longer periods of study.

VI. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

It is to be noted that the subjective analysis shown here resulted in windfields undoubtedly more accurate than the GBA, partly because of the data in addition to that available to the operational GBA, and partly due to use of techniques not presently a part of the operational GBA program. It is considered, however, that the methods utilized are within the framework of the existing capability of the FNWC computer and quality-control personnel. It is gratifying to note that, since the advent of this study; (a) FNWC is in daily receipt of additional upper-air reports from the Southern Hemisphere, (b) programs are being written to incorporate ATS cloud-vector motions, (c) satellite photographs are copied almost daily in FNWC's operations center for use in the analyses and (d) the coded analyses are being utilized on a daily basis by the operational personnel.

As a matter of consequence, data are the key to good analysis. It is a well known fact that increasing data will result in more accurate analyses and certainly more accurate prognostic charts. In the GBA program a scarcity of data necessitates a gradual return of the winds to climatology. Observations, if scarce in number, will be materially smoothed by the variational scheme or even rejected. It is in this area that the personnel of FNWC must exercise their judgment and quality control so as to determine if the

analysis is correct, or if the analysis should be changed to incorporate the rejected report.

Many wind climatologies have been developed over the years using varying periods of data. In this study, while the climatologies utilized were different, the results attained were not significantly different with the exception of the shorter-period current climatology. For example, in the eight-day test, the current climatology produced a RMSE that was approximately 10% better than the other climatologies, which indicates that there was a high correlation between the most recent observations and short-period weather regimes.

There were no marked differences (less than 5%) in the minimum RMSE between each of the climatologies used during the longer 14-day period. When comparing the verifying analysis with the first guess produced by the other climatologies, FNWC produced the smallest RMSE. This was an unexpected result because of the type and density of data basic to this climatology. Due to the lack of aircraft reports, which were incorporated in the other climatologies, it was expected that FNWC would not have fared as well for this largely sparse data region.

The 100/0 persistence/climatology values of Figures 10 and 11 represent the 24-hour or interdiurnal variation of the wind. It is significant that the RMSE associated with the optimum persistence/climatology combination is 18-33%

less than the interdiurnal variability of the wind. Another interesting aspect of the study involved the percentage combination of persistence and climatology as a function of the wind steadiness. The 14-day period value of 29.3 kt was slightly less than the 29.7 kt of the eight-day period. It is anticipated that the RMSE value can be lowered by this method when optimum persistence/climatology relations with the wind steadiness have been determined.

There is reason to believe that a short-period climatology can consistently produce a first-guess wind that is as accurate as any produced by long-term climatology. Utilization of a short-term climatology could be made flexible enough in length to accommodate the monsoonal changes or other periodicities occurring in certain areas.

Additional studies should be undertaken to determine the RMSE in the same manner for each day in order to determine what period or length of time produces the optimum first guess with the minimum RMSE. Additionally, it should be determined if there is any significant saving of computer storage by utilizing a short-term climatology vice the long-term climatology currently being utilized.

This study did not include any data other than from the 0000 GMT time. Further tests should be done including the 1200 GMT data. It is recommended that further study be done for a later time period, perhaps a two-week period in each season to test the feasibility of the short-term climatology and to verify the results attained in this study.

APPENDIX

CASE STUDY OF SURFACE AND 250-mb WIND ANALYSES FOR 8-22 MARCH 1972

Objective analyses or forecast schemes generally require a first guess which is based on the most recent history analysis. Any analysis, whether objective or subjective, will be improved if the maximum data available are put into the program. Therefore, a primary objective of this thesis study was to enhance the Global Band Analysis (GBA) through the addition of all available data, as previously discussed in Section III, and to produce a high quality subjective analysis (SUBAN) the type of which could be reproduced by the computer. This Appendix describes the comparison of the GBA to the SUBAN for various dates. Discussion will be limited to charts with salient features which illustrate the differences between the GBA and the SUBAN.

The area selected for this study contained both data-dense and data-sparse areas. It was also necessary to include large areas where there were very few data or none at all available to the GBA for long periods of time (more than five days). This was done to test the influence that new observations would have on the GBA which returns winds to climatology at the rate of about 20% per day; hence, after about five days of no data, the GBA would be a replica of climatology.

The area chosen was the Pacific Ocean from 60N to 40S and from 120E to the west coast of North and South America. Two levels, the surface and 250 mb, were chosen to test the horizontal continuity and vertical consistency. Continuity is a part of the GBA in that persistence is used for a first-guess analysis, but vertical consistency was not inherent in the GBA until a later date (Lewis 1972).

The 0000 GMT time was selected for these charts because of the availability of ATS I and ATS III satellite pictures and the numerous resulting cloud-motion winds produced at NESS. Also, this time is during daylight over all the Pacific which corresponds to the time of the maximum number of ship reports.

A primary consideration in this study is that the data utilized could be available in real time to the analysis program or to the Quality Control Section, FNWC. Comparisons of the GBA and SUBAN are presented in the following paragraphs.

1. <u>0000 GMT 8 March 1972</u>

This analysis was supported by many cloud-vector winds and good ATS I and ATS III pictures. Because it was the first analysis in the series, most features of the surface and 250-mb levels were examined in detail to provide a base for continuity.

a. Surface Wind and Sea-level Pressure Analyses (Figures 14 and 15)

In the normally data-dense Northern Hemisphere there is excellent correlation between the wind fields and the pressure systems. The GBA, as based on the Numerical Variational Analysis (NVA) scheme, has accommodated to the wind field very well; however, there is a tendency for the GBA to yield an oversmooth version of the pressure field. This is apparently due to the relative weighting factors given successive grid-point scans and the grid size of the NVA scheme. It is noted, however, that there are many wind reports in this and succeeding analyses which were rejected by the GBA (Figure 14), but accommodated by the SUBAN (Figure 15).

In the eastern Pacific Ocean tropical areas a zone of convergence is apparent on the ATS photographs (Figures 18 and 19), pictured as a cloud band just south of the equator near 110W and supported by low-level cloud-vector motions. The GBA in this area, although a function of minimal data, suggests at least a slightly divergent flow which is in agreement with the FNWC climatology used as a basis for the GBA.

The SUBAN based on cloud-vector motion in the Southern Hemisphere indicates an uninterrupted easterly flow extending from 5N to 10S, while the GBA shows mostly climatological dependence in this same area. Throughout this period the GBA was predominantly climatological in nature due to the scarcity of data. In contrast, the SUBAN

shows cyclonic vortices east of Australia that are consistent with the pressure analysis. In the vicinity of 15S and 170W on the SUBAN there is evidence of a vortex based on ATS III and conventional data which the GBA indicates only as an area of weak cyclonic curvature.

b. 250-mb Wind Analyses (Figures 16 and 17)

Cloud-vector winds, satellite interpretation from ATS III and the use of rejected winds indicate a vortex at 42N 157W on the SUBAN (Figure 17), while in contrast the GBA has southwesterly flow with cyclonic curvature. Elsewhere in the Northern Hemisphere the lows and troughs of the two analyses agree quite well. The subtropical ridge has two cells at 157E and 172W longitude while the GBA indicates a single cell at 157W.

Cloud-vector motions and actual data show a stong subtropical jet stream in excess of 150 knots from China eastward to 145W; however, the GBA indicates winds of 150 knots from 165E to 180 longitude. This is apparently due to the inherent smoothing of the NVA scheme.

The greatest variations between the SUBAN and GBA occur in the Southern Hemisphere. They are apparently due to minimal data in the area and the subsequent return to climatology as noted previously. Cloud vectors and rejected winds show a strong ridge east of Australia and a pronounced tropical upper tropospheric trough, TUTT, (Sadler 1970), in the mid-equatorial Pacific extending south into mid-latitudes. A well documented climatological feature is

the persistent anticyclone over most of South America (Dean 1971).

2. <u>0000 GMT 9 March 1972</u>

The SUBAN was supported by many observations at both levels plus a large number of cloud-vector winds and excellent ATS photographs. Many rejected winds were utilized, particularly in the Southern Hemisphere.

a. Surface-Wind and Sea-level Pressure Analyses (Figures 20 and 21)

The Northern Hemisphere continues to be in good agreement on both analyses. A zone of convergence persists in the eastern tropical Pacific Ocean supported by low-level cloud-vector winds (Figure 21) and ATS III (Figure 22); however, the GBA continues to show the climatological influence in the tropics and Southern Hemisphere. The western South Pacific area is dominated by light winds and numerous vortices; however, the SUBAN, supported by ATS I (Figure 23) and rejected winds, indicates a developed vortex near 15S 178E, which is in an area of cyclonic curvature on the GBA.

b. 250-mb Wind Analyses (Figures 24 and 25)

The vortex in the Gulf of Alaska, on the SUBAN (Figure 25) shows good continuity from the prior day supported by the cloud-vector winds and satellite photos. This same vortex is in agreement with the GBA.

The low that was south of Kamchatka is continued on the SUBAN based on rejected winds, but the GBA shows a

complex trough extending southeast and east. Another major difference in the two analyses is the location and strength of the ridge in the north central Pacific Ocean. Cloud vectors and rejected winds support the SUBAN. Another difference is the weaker subtropical jet of the GBA versus the stronger SUBAN jet.

The divergence aloft over the eastern tropical Pacific Ocean shows good vertical consistency with the low-level convergence in the same area. The Southern Hemisphere TUTT has maintained itself on the SUBAN, but the GBA, due to sparse data, continues to be dominated by climatology, rejecting winds which would have influenced the analysis. It is to be noted here, that the SUBAN has also rejected some cloud-vector winds when they do not fit the analysis.

3. 0000 GMT 10 March 1972

There were a small number of cloud-vector winds at this map time, but good satellite pictures and limited SIRS data were available. SIRS data provided a means of determining a gradient wind in the small areas where they were plotted.

a. Surface Wind and Sea-Level Pressure Analyses (Figures 26 and 27)

The SUBAN (Figure 27) and the GBA (Figure 26) agree on the Northern Hemisphere analysis which again lends credence to the importance of having sufficient data versus dependence on climatology.

The SUBAN, supported by ATS I (Figure 30), shows the western portion of the Southern Hemisphere continuing

under the influence of many vortices associated with mid-latitude troughs and tropical shear lines. In the eastern South Pacific area, convergence in the tropics and a large anticyclone continue to dominate. In contrast, climatology and persistence continue to dominate the GBA.

b. 250-mb Wind Analyses (Figures 28 and 29)

The SUBAN (Figure 29) maintained its continuity in the Northern Hemisphere lows and associated trough/ridge relationships with the aid of cloud-vector winds and interpretation of ATS I and III (Figures 30 and 31) photographs. The GBA, due to sparse or no data in key areas, could neither continue the eastern low nor develop the central Pacific cyclone.

TUTT and ridge relationships were easily maintained in the Southern Hemisphere on the SUBAN despite lack of additional reports. The GBA agreed in part with the SUBAN TUTT, but elsewhere in the areas of the anticyclones over the western portion the small number of reports were inadequate to overcome climatology and persistence. Divergence over the eastern tropical area was apparent on both analyses.

4. <u>0000 GMT 15 March 1972</u>

Although there were differences in the SUBAN and GBA between 10 and 15 March, the salient features have already been considered. On the 15th, interest is centered on the surface in the Southern Hemisphere, particularly on the series of vortices from 110W to 170E. The GBA (Figure 32)

analyzes the situation as weak cyclonic curvature, yet the SUBAN (Figure 34), supported by ATS I(Figure 33), shows numerous vortices in an apparent frontal trough. It appears that the smoothing effects of climatology and persistence in the NVA scheme are stronger than the effects caused by too few data.

5. <u>0000 GMT 18 March 1972</u>

The surface analysis was unavailable on this day, but the 250-mb GBA and SUBAN (Figures 35 and 36), respectively, had some interesting correlations and differences. The anticyclone over the southwestern United States has persisted for some time and is in excellent agreement with the GBA (Figure 35). However, there are some differences in the upper troughs flanking the anticyclone, which are confirmed on the SUBAN by the cloud-vector winds and GBA rejected reports. The GBA shows strong horizontal directional shear to the southeast of the anticyclone which is not so pronounced on the SUBAN. Additionally, there is an induced cyclone to the southwest of this high which is supported by SIRS data and cloud-vector motions.

In addition, cloud-vector winds and GBA rejected reports support the split of the TUTT in the Southern Hemisphere. Compare this to the climatology and persistence-dominated GBA Southern Hemisphere analysis.

6. <u>0000 GMT 19 March 1972</u>

Teletype (canned) analyses, received from Australia, New Zealand and Argentina through FNWC, were utilized on the

SUBAN (Figure 38). Limited SIRS data in the Northern Hemisphere and a large number of cloud-vector winds were available, particularly in the Southern Hemisphere.

a. Surface-Wind and Sea-Level Pressure Analyses (Figures 37 and 38)

The significant feature of this day is the tropical cyclone at 18S 172E which has been developing since the fifteenth. The GBA (Figure 37) shows a light wind area with cyclonic curvature, while the SUBAN (Figure 38) utilizing the available data, ATS I (Figure 39) and the canned analysis shows a well-developed tropical cyclone. An additional feature is the apparent frontal system on ATS I which extends north/south between 135W and 150W in the Southern Hemisphere and is portrayed as a well-developed trough on the SUBAN versus a weak area of cyclonic curvature on the GBA.

7. <u>0000 GMT 20 March 1972</u>

Again on this date the surface level is of primary interest. Because of insufficient data on the SUBAN (Figure 41), FNWC has introduced into the data "bogus" or fabricated data in the vicinity of the tropical cyclone in the Southern Hemisphere to force the computer to analyze this storm. It is noted that the "bogus" data were entered and the resultant GBA (Figure 40) position is three degrees of latitude northeast of the actual position. However, canned analysis from the area and use of rejected reports (apparently rejected because of the bogus data) place the storm more accurately on the SUBAN.

8. <u>0000 GMT 21 March 1972</u>

This day's analysis was aided by Southern Hemisphere canned maps, limited cloud-motion vectors, satellite photos and rejected winds.

a. Surface-Wind and Sea-Level Pressure Analyses (Figures 42 and 43)

The tropical cyclone noted on prior analyses in the Southern Hemisphere is in good agreement on both analyses; however, the pressure center is two degrees of latitude to the northeast of the SUBAN (Figure 43) wind center. The canned analysis substantiates the position of the wind center as does ATS I (Figure 44). A second cyclone appears as a trough on the GBA (Figure 42), but the actual winds and ATS I show a vortex at this position.

b. 250-mb Wind Analyses (Figures 45 and 46)

Two upper cyclones are apparent in the Northern Hemisphere on the SUBAN (Figure 46) with the aid of cloud vector winds and ATS I. The cyclone near 34N 176E is in an area of little data, while the second southeast of the Aleutians is supported by reported winds. In contrast, the GBA (Figure 45) has analyzed troughs in both areas.

In the Southern Hemisphere, the TUTT continues to maintain continuity. The anticyclones west of the TUTT on the SUBAN are based entirely on conventional data whereas the GBA shows a relatively smooth west to east flow which is basic to climatology and persistence.

9. <u>0000 GMT 22 March 1972</u>

In this final analysis there is good support from all sources except SIRS data.

a. Surface-Wind and Sea-Level Pressure Analyses (Figures 47 and 48)

Again, the significant feature of this SUBAN (Figure 48) is the tropical cyclone located at 25N 165E. The system has progressed smoothly to the south; however, the GBA (Figure 47), has been inconsistent in its analysis. "Bogus" data were entered into the computer to position the storm apparently 2-3 degrees to the northwest of the actual position on the SUBAN which resulted in the GBA position being off a similar amount.

b. 250-mb Wind Analyses (Figures 49 and 50)

History and actual winds plus the cloud-vector motion and rejected winds indicate multiple anticyclones and intensification of the TUTT on the SUBAN (Figure 50) as compared to the relatively smooth west to east flow that is climatologically influenced on the GBA.

In the Northern Hemisphere the cyclone southeast of the Aleutians is in agreement with the GBA; however, in the central Pacific area apparent lack of data prevents the GBA from indicating the cyclone shown by the cloud-vector winds.

10. <u>General Conclusions</u>

In the foregoing comparisons, it was found that the GBA, if provided adequate data, can correctly analyze any synoptic situation. On a subsynoptic scale, however, the

grid size of 150 nmi in the tropics is not fine enough to cope with small tropical cyclones as was evidenced during the latter half of the study.

Of course, the lack of data in many areas, particularly the Southern Hemisphere, causes the GBA to be primarily under the influence of climatology. Recent conversations with personnel at FNWC indicate that additional data are getting into the GBA, particularly in the Southern Hemisphere upper levels. This has alleviated the problem somewhat. Programs are being written to incorporate SIRS data and cloud-vector winds into the NVA scheme.

Because of insufficient data, major features such as the TUTT in the Southern Hemisphere, and synoptic-scale cyclones in the Northern Hemisphere were greatly smoothed. However, as data inputs increase, these problems should also disappear.

PERCENTAGE COMBINATION OF PERSISTENCE/CLIMATOLOGY

		100/00	90/10	80/20	75/25	70/30	60/40	50/50	40/60	30/70	25/75	20/80	10/90	00/100
CURRENT	8 day	39.0	36.8	34.9	34.0	33.2	31.7	30.5	29.6	29.0	28.9	28.8	28.9	29.4
	14 day	40.8	37.9	35.9	34.9	34.0	32.4	31.0	30.0	29.4	29.2	29.1	29.2	29.7
FNWC	8 day	39.0	36.9	35.2	34.4	33.7	32.5	31.7	31.1	31.0	31.1	31.3	31.9	32.9
	14 day	40.8	37.6	35.3	34.2	33.2	31.4	29.9	28.8	28.1	28.0	27.9	28.2	28.9
SADLER	8 day	39.7	37.4	35.6	34.8	34.0	32.8	31.9	31.5	31.5	31.7	32.0	32.8	34.1
	14 day	42.1	39.0	36.8	35.7	34.7	32.8	31.2	29.9	29.0	28.6	28.4	28.2	28.4
FWC PEARL	8 day	39.7	37.6	35.9	35.2	34.5	33.4	32.7	32.4	32.4	32.6	32.8	33.6	34.8
	14 day	42.1	39.0	36.7	35.7	34.7	32.9	31.3	30.1	29.2	29.0	28.8	28.7	29.1

AS A FUNCTION OF WIND STEADINESS (WS)— 8 day - 29.7
14 day - 29.3 (See text pages 23 and 27)

TABLE I. RMSE (kt) for first-guess 250-mb winds for various combinations of 24-hour persistence and climatology for the eighth (16 March 1972) and fourteenth (22 March 1972) days.

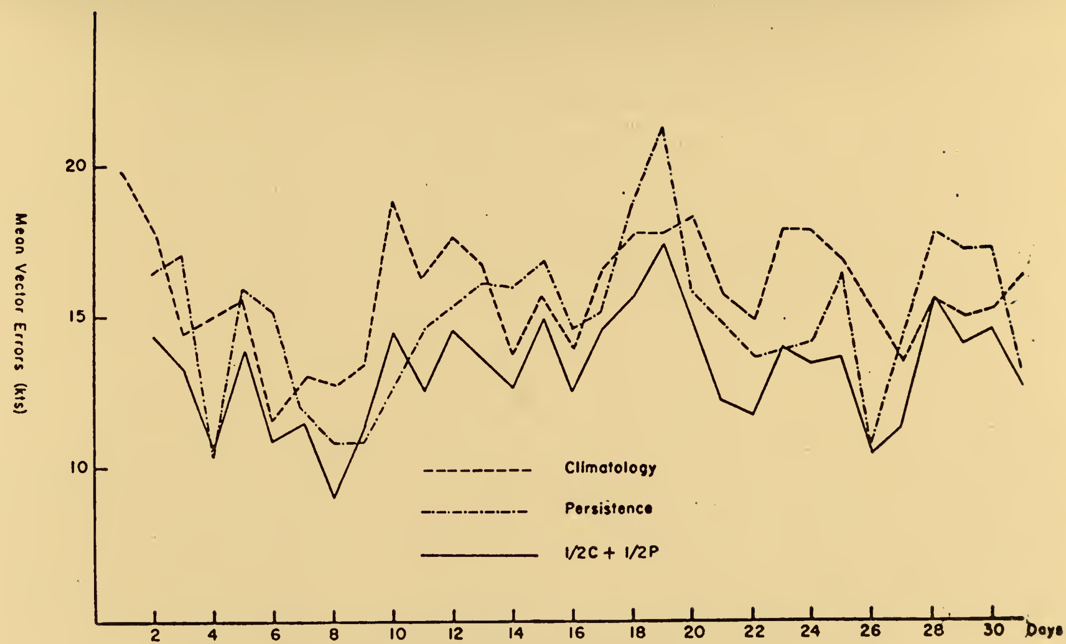

Figure 1. Mean vector error (kt) of 24-hour forecasts of 30,000-foot winds over the Central Pacific Ocean for May 1959, based on climatology, persistence and an equal weighting of climatology and persistence. [After Lavoie and Wiederanders (1960)].

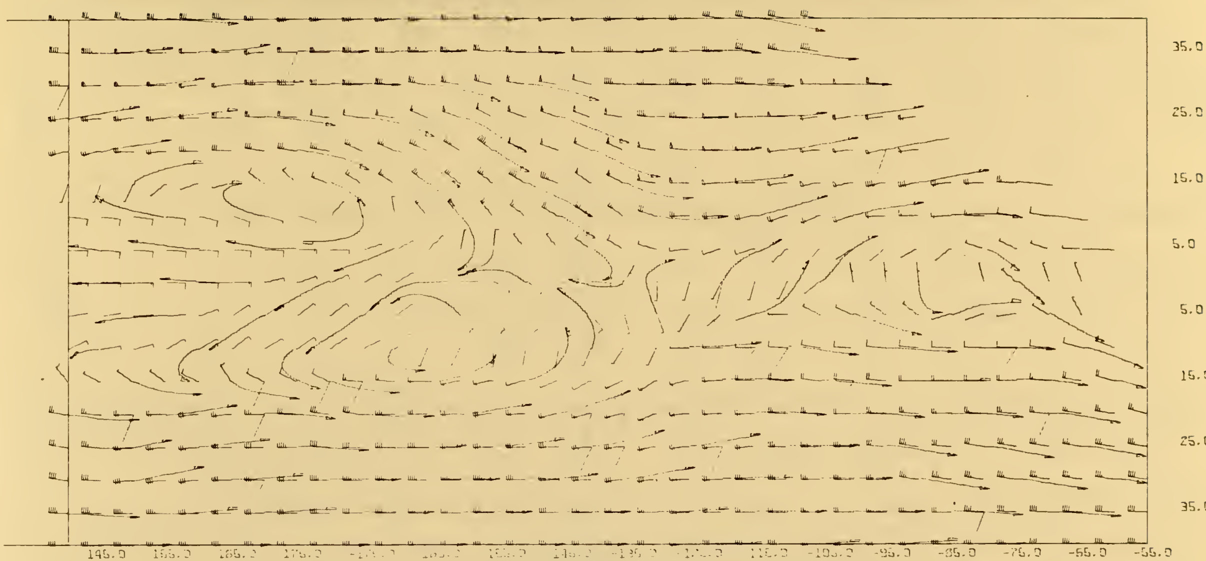

FIGURE 2. MARCH CLIMATOLOGY OF 250MB WINDS (KT) UTILIZED AT FNWC

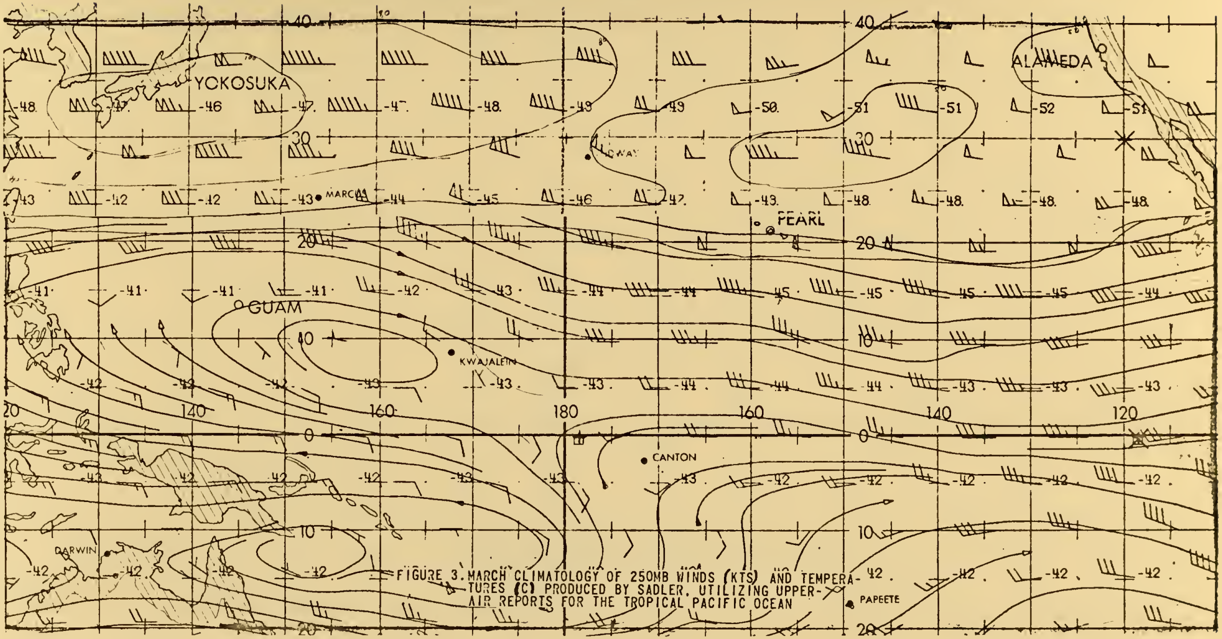

FIGURE 3. MARCH CLIMATOLOGY OF 250MB WINDS (KTS) AND TEMPERATURES (C) PRODUCED BY SADLER, UTILIZING UPPER-AIR REPORTS FOR THE TROPICAL PACIFIC OCEAN

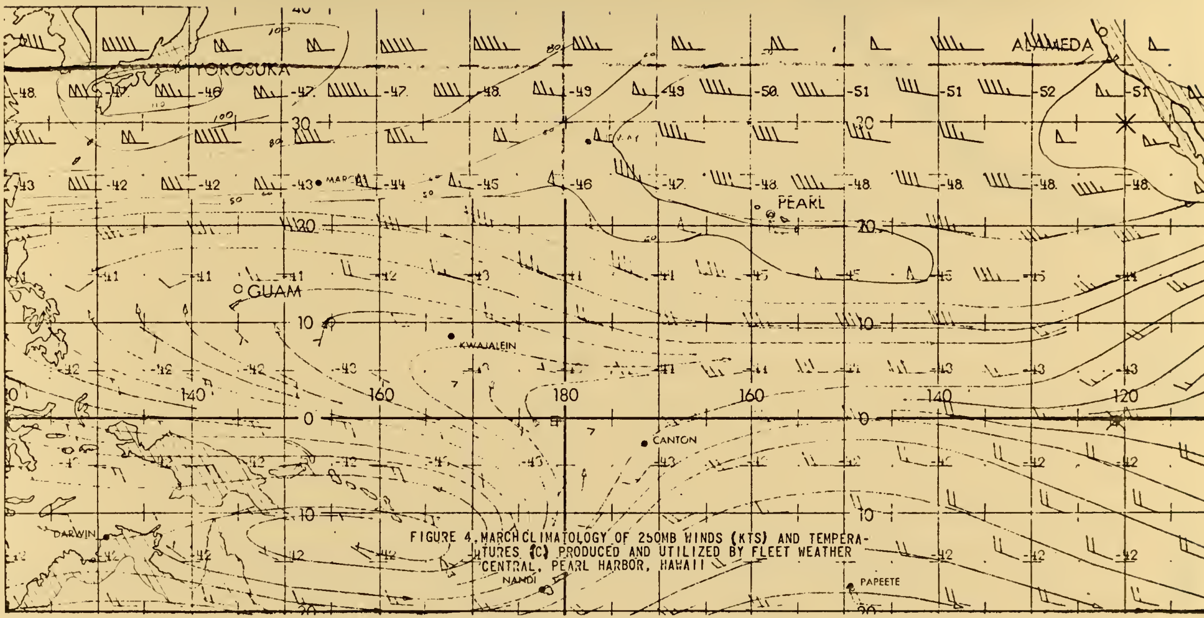

FIGURE 4. MARCH CLIMATOLOGY OF 250MB WINDS (KTS) AND TEMPERATURES (C) PRODUCED AND UTILIZED BY FLEET WEATHER CENTRAL, PEARL HARBOR, HAWAII

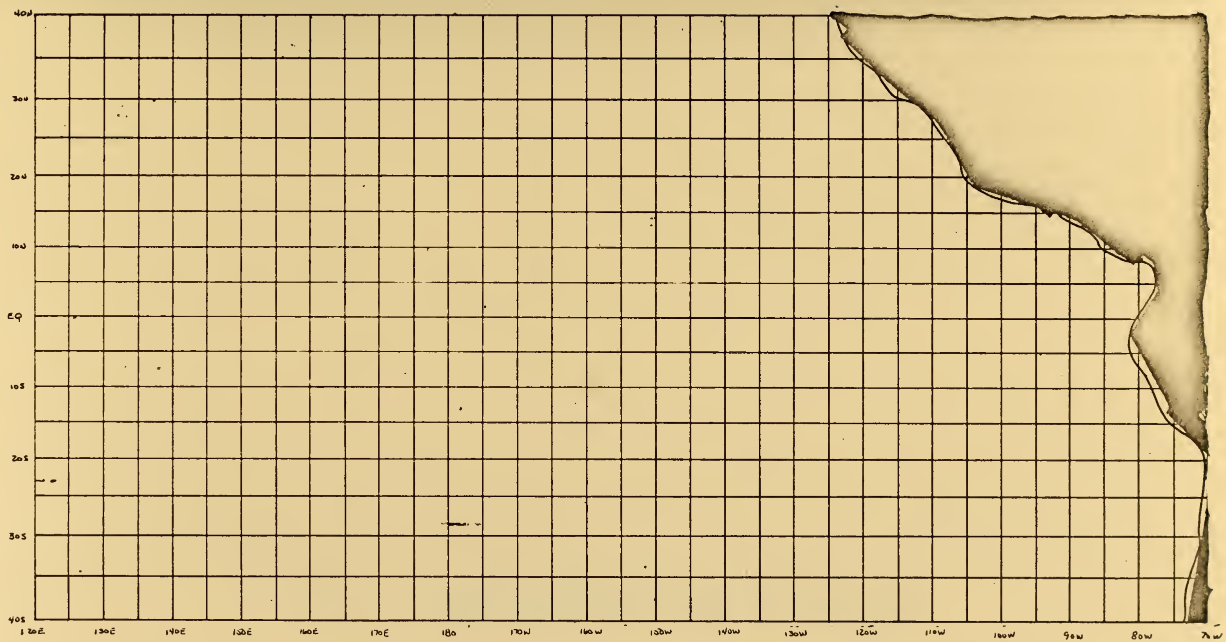

FIGURE 5. FIVE DEGREE LATITUDE LONGITUDE GRID USED FOR GRID-POINT DATA

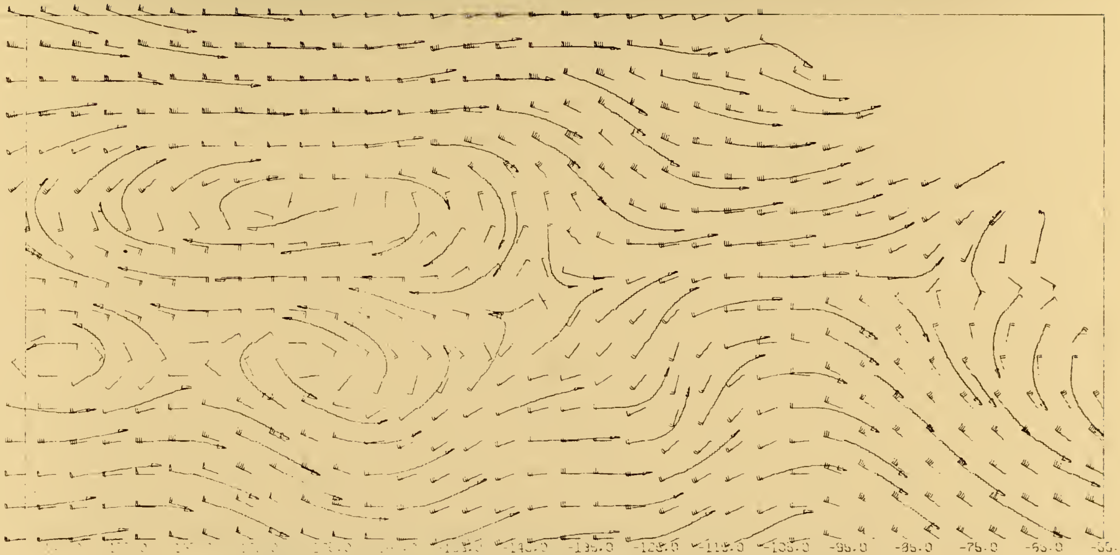

FIGURE 6. CURRENT CLIMATOLOGY OF 250MB WINDS (KT) AS DERIVED FROM A 14-DAY PERIOD (8-22 MARCH 1972)

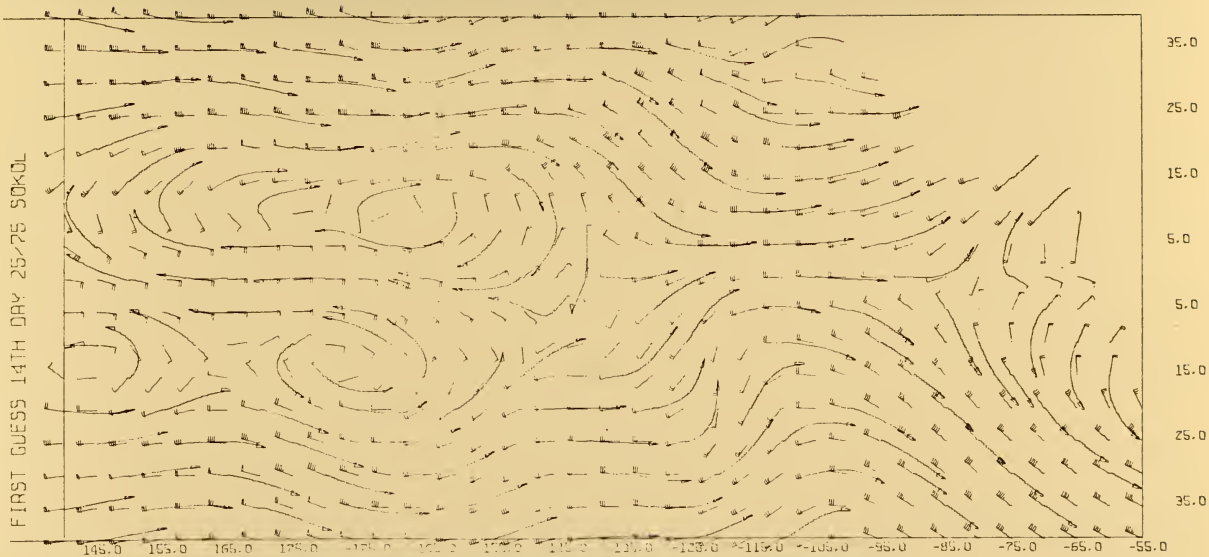

FIGURE 7. FIRST GUESS OF 250MB WINDS (KT) FOR THE 14TH DAY (22 MARCH 1972)

FIGURE 8. VECTOR ERROR OF THE 250MB FIRST-GUESS WINDS (KT) FOR THE 14TH DAY (22 MARCH 1972)

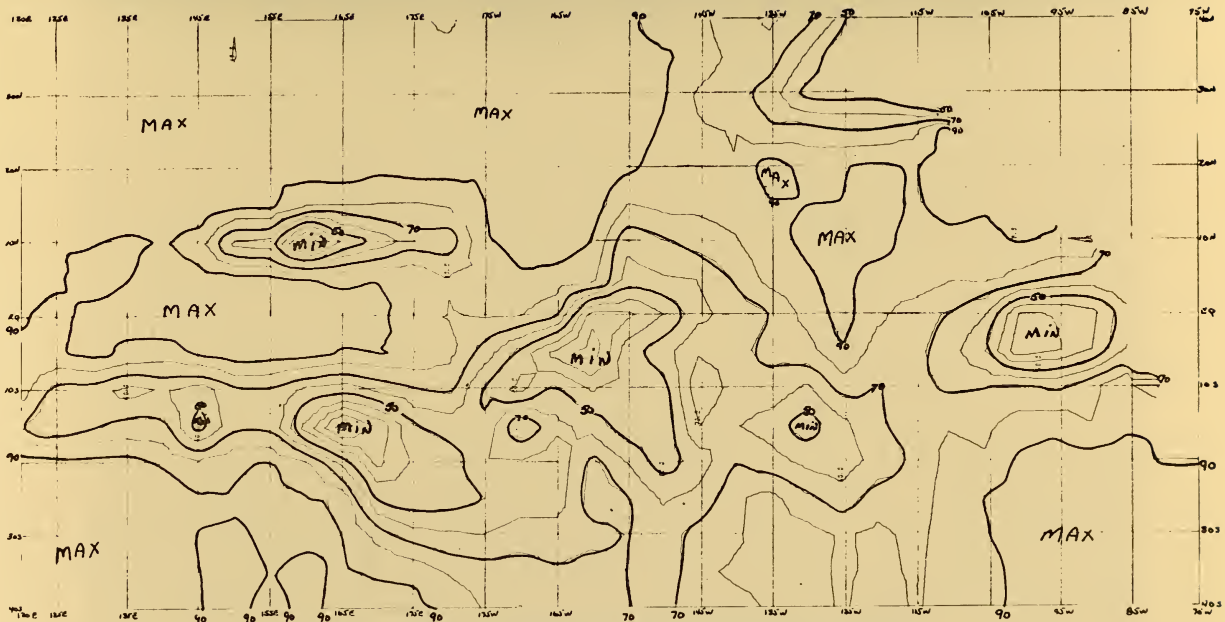

FIGURE 9. CHART OF 250MB WIND STEADINESS IN PERCENT BASED ON A 10-DAY PERIOD (8-18 MARCH 1972).

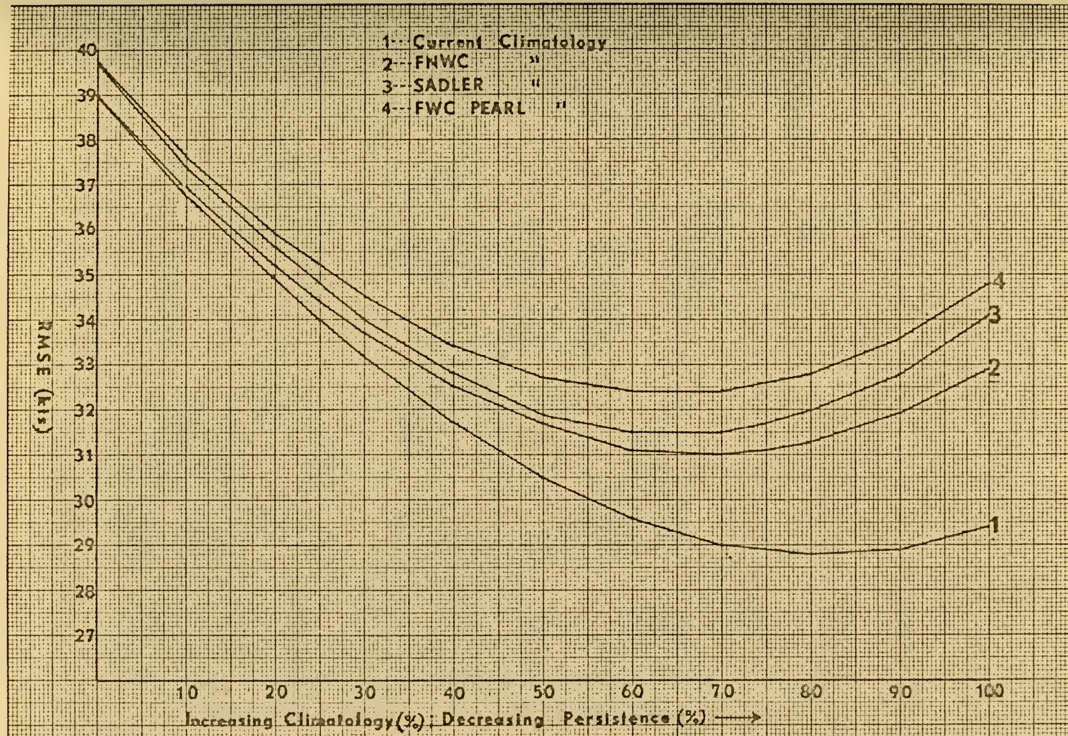

Figure 10. RMSE's of 250-mb winds (kt) for the 8th day for various climatologies as a function of the relative weighting of climatology, (increasing climatology, decreasing persistence along abscissa).

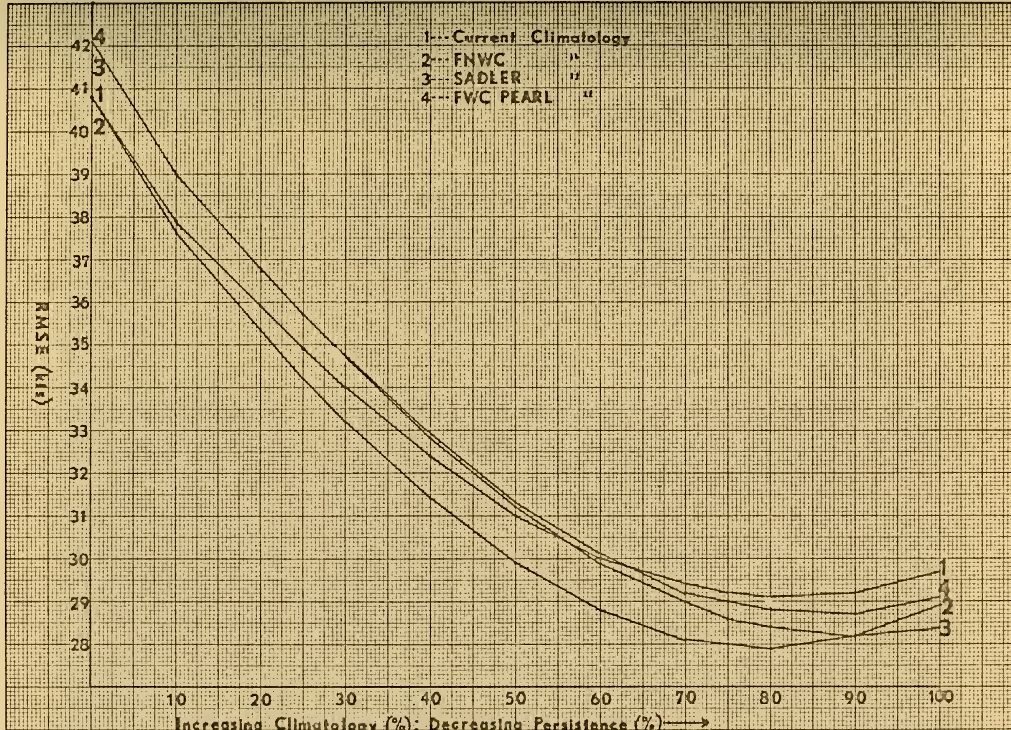

Figure 11. RMSE's of 250-mb winds (kt) for the 14th day for various climatologies as a function of the relative weighting of climatology, (increasing climatology, decreasing persistence along abscissa).

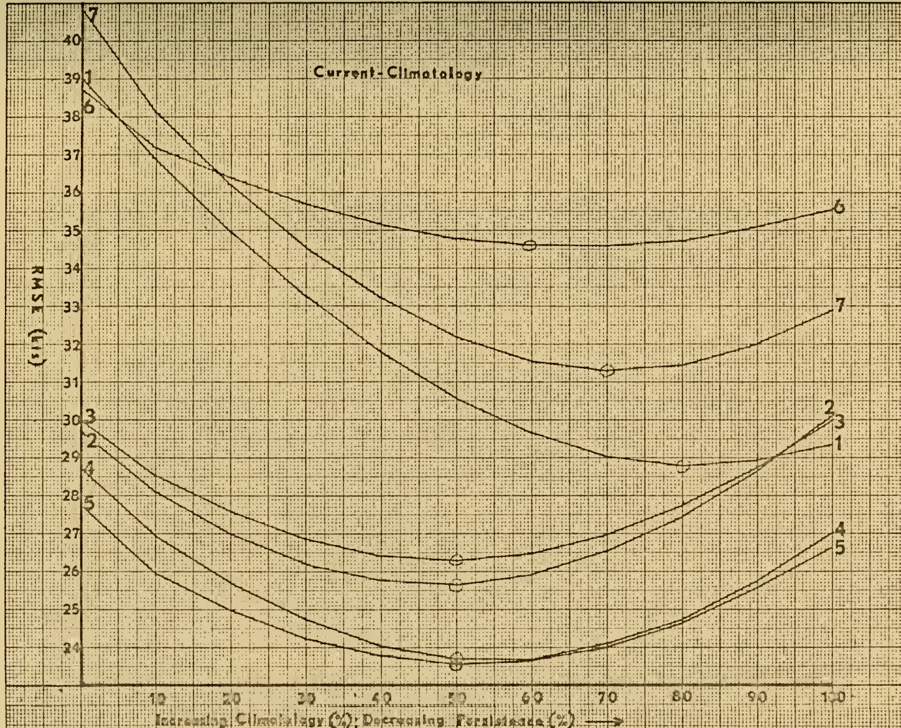

Figure 12. RMSE's of 250-mb winds (kt) for adjacent overlapping 8 day periods from 16 March to 22 March 1972 utilizing only the current-climatologies and persistence. (1 = 16 March, 2 = 17 March, 3 = 18 March, etc.)

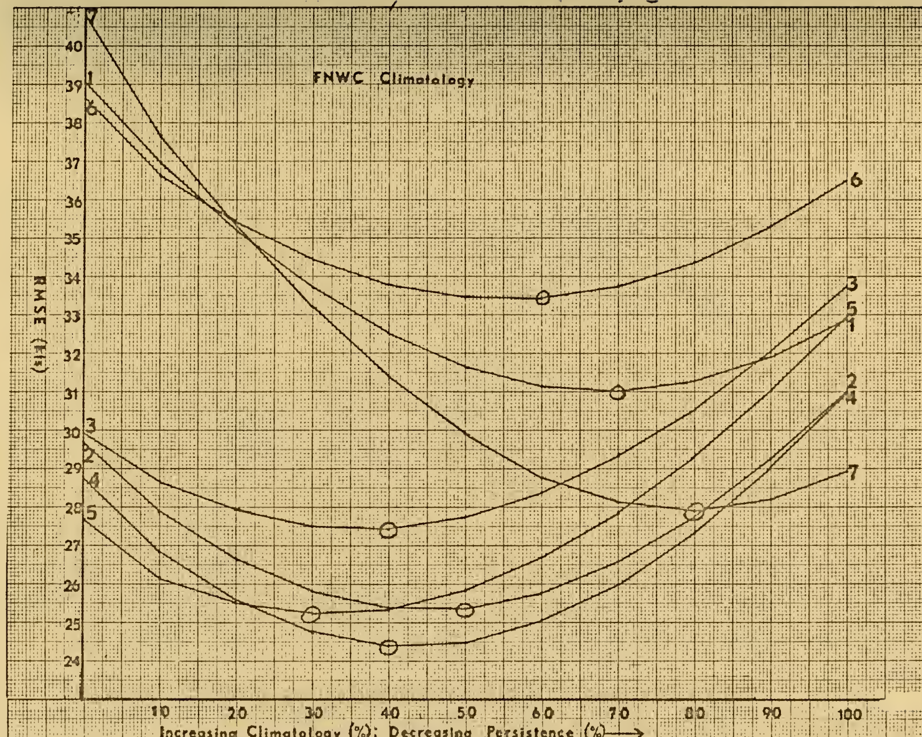

Figure 13. RMSE's of 250-mb winds (kt) for adjacent overlapping 8 day periods from 16 March to 22 March 1972 utilizing only the climatology of FNWC and persistence. (1 = 16 March, 2 = 17 March, 3 = 18 March, etc.).

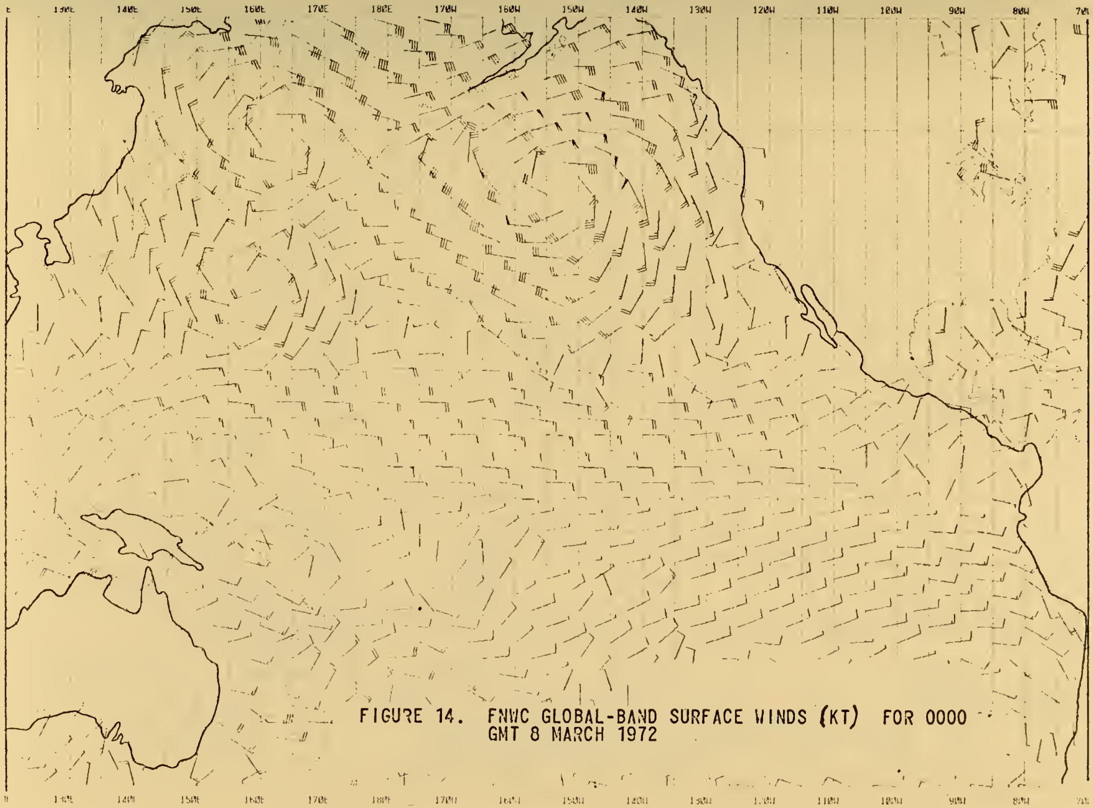

FIGURE 14. FNWC GLOBAL-BAND SURFACE WINDS (KT) FOR 0000 GMT 8 MARCH 1972

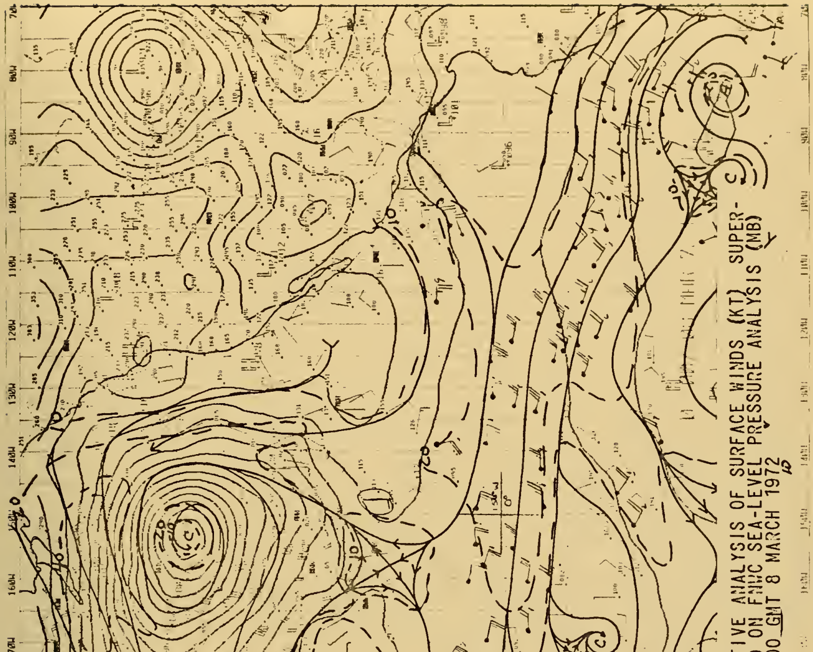

FIGURE 15. SUBJECTIVE ANALYSIS OF SURFACE WINDS (KT) SUPER-IMPOSED ON FNWC SEA-LEVEL PRESSURE ANALYSIS (MB) FOR 0000 GMT 8 MARCH 1972

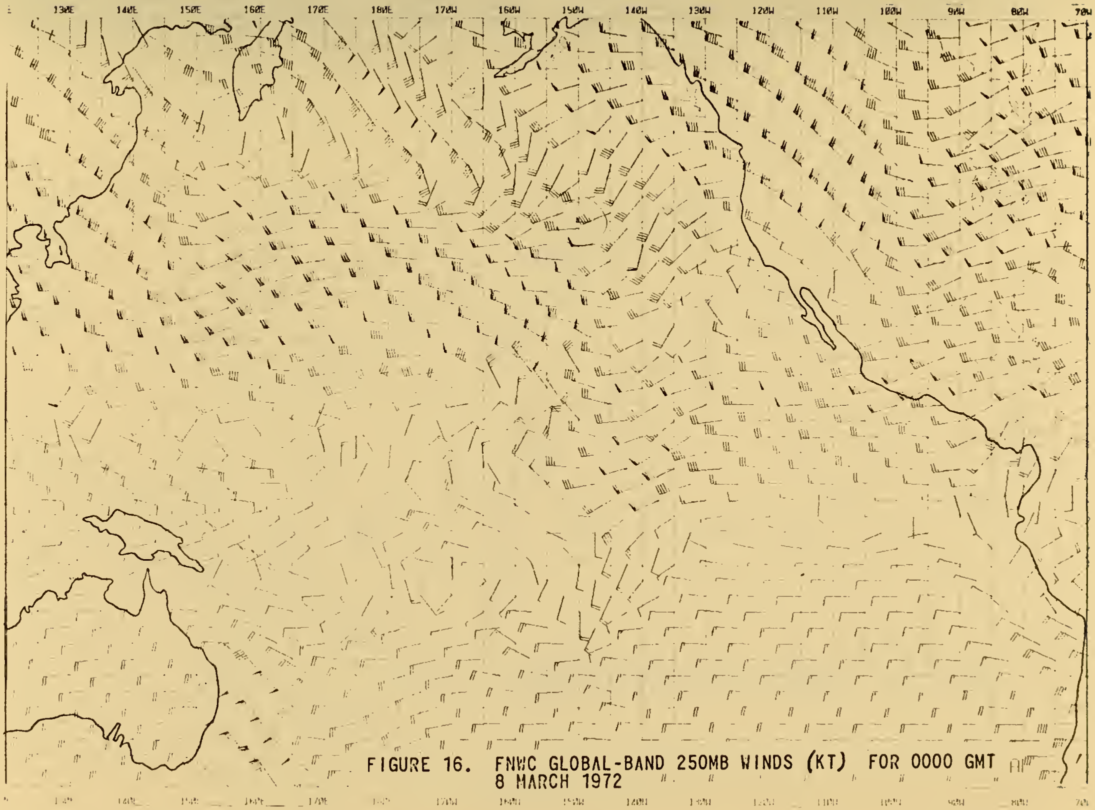

FIGURE 16. FNWC GLOBAL-BAND 250MB WINDS (KT) FOR 0000 GMT
8 MARCH 1972

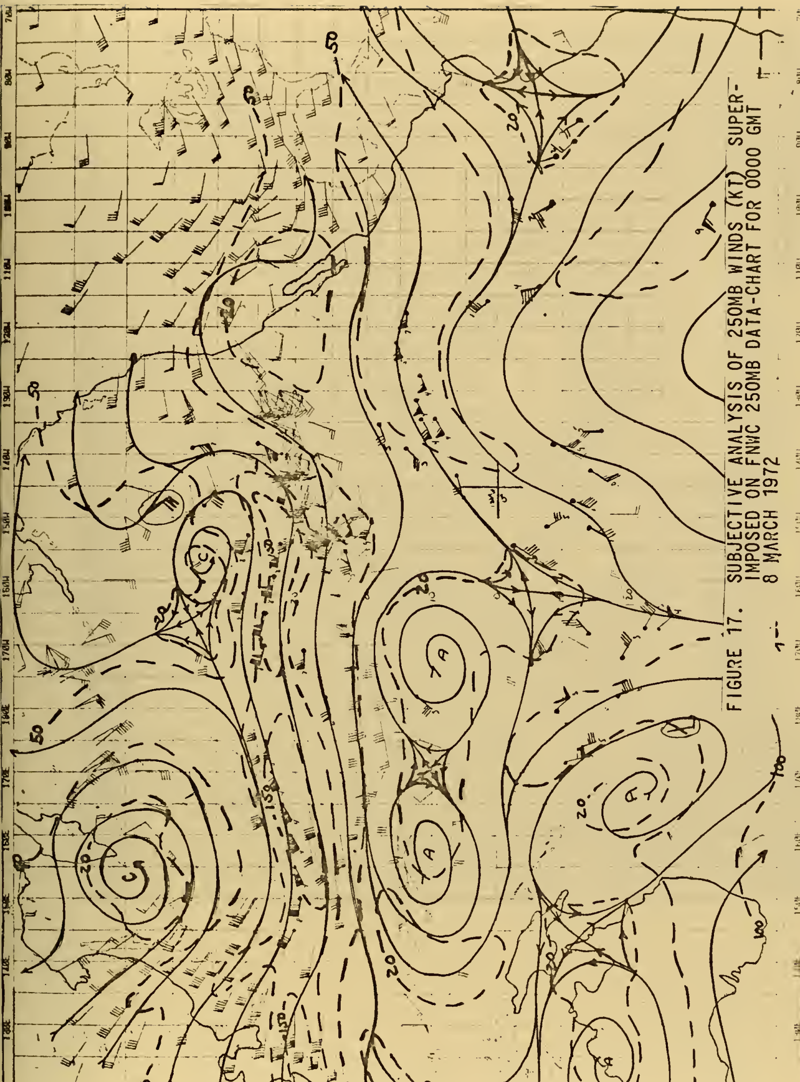

FIGURE 17. SUBJECTIVE ANALYSIS OF 250MB WINDS (KT) SUPER-IMPOSED ON FNWC 250MB DATA-CHART FOR 0000 GMT 8 MARCH 1972

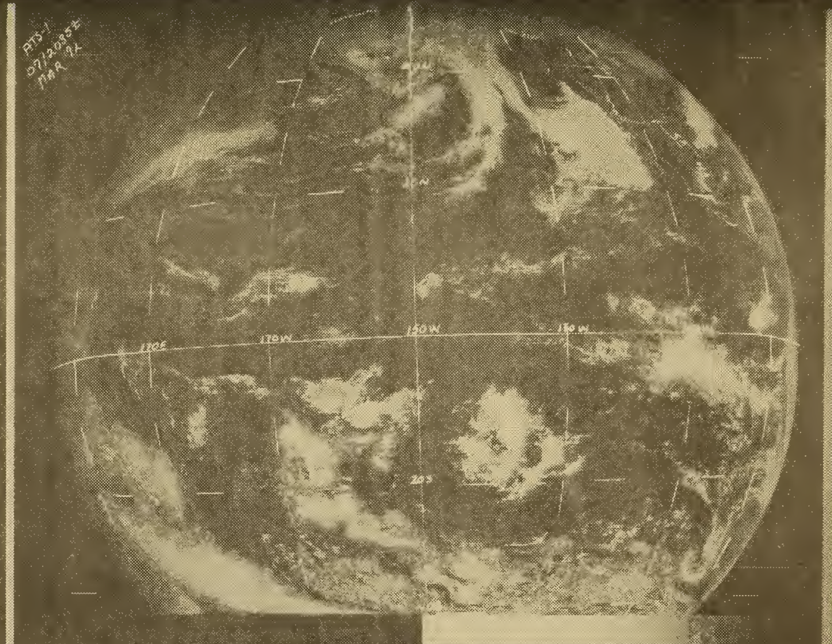

Figure 18. ATS I Satellite photograph for 2035 GMT 7 March 1972.

Figure 19. ATS III Satellite photograph for 1743 GMT 7 March 1972.

FIGURE 20. FNWC GLOBAL-BAND SURFACE WINDS (KT) FOR 0000 GMT 9 MARCH 1972

FIGURE 21. SUBJECTIVE ANALYSIS OF SURFACE WINDS (KT) SUPER-IMPOSED ON FNWC SEA-LEVEL PRESSURE ANALYSIS (MB) FOR 0000 GMT 9 MARCH 1972

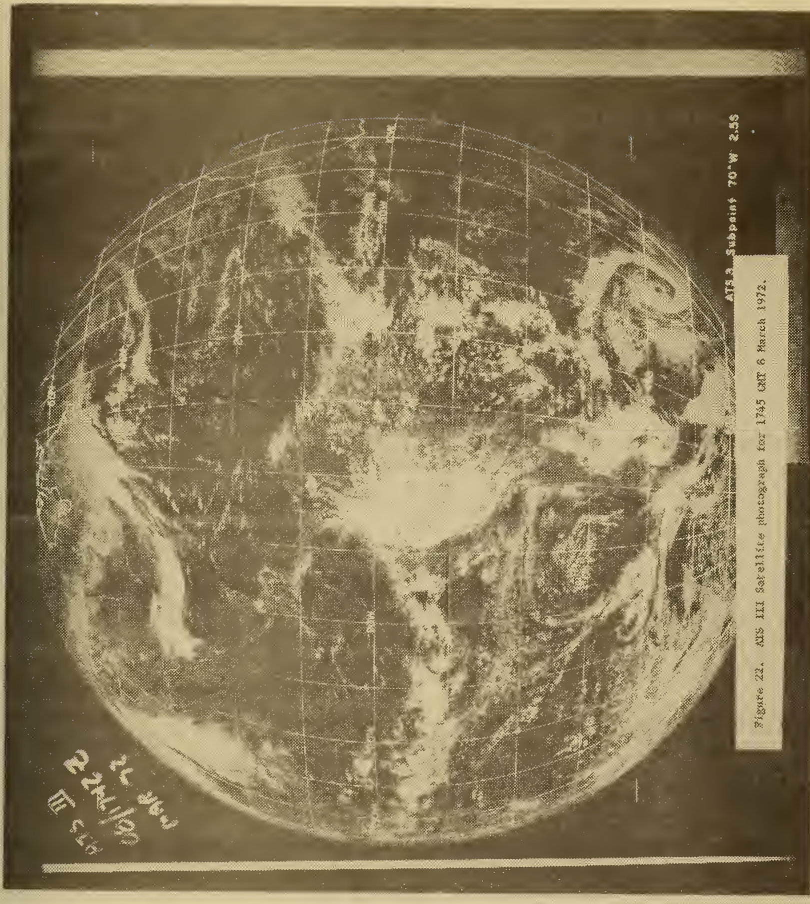

Figure 22. ATS III Satellite photograph for 1745 GMT 6 March 1972.

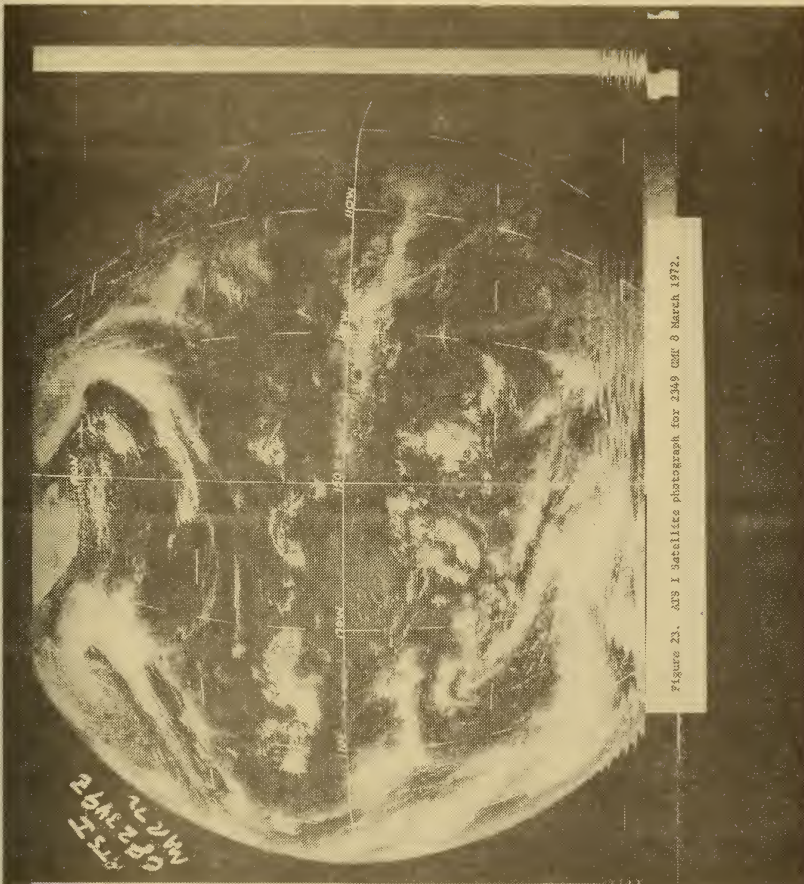

Figure 23. ATS I Satellite photograph for 2349 GMT 8 March 1972.

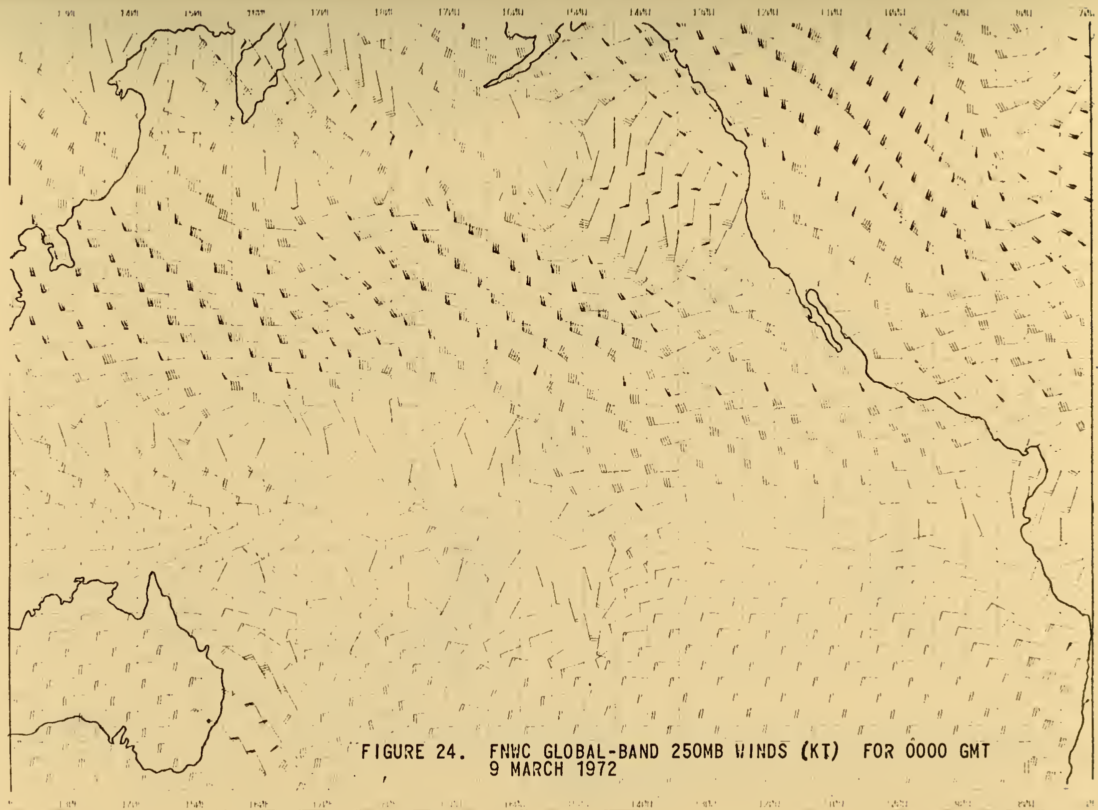

FIGURE 24. FNWC GLOBAL-BAND 250MB WINDS (KT) FOR 0000 GMT 9 MARCH 1972

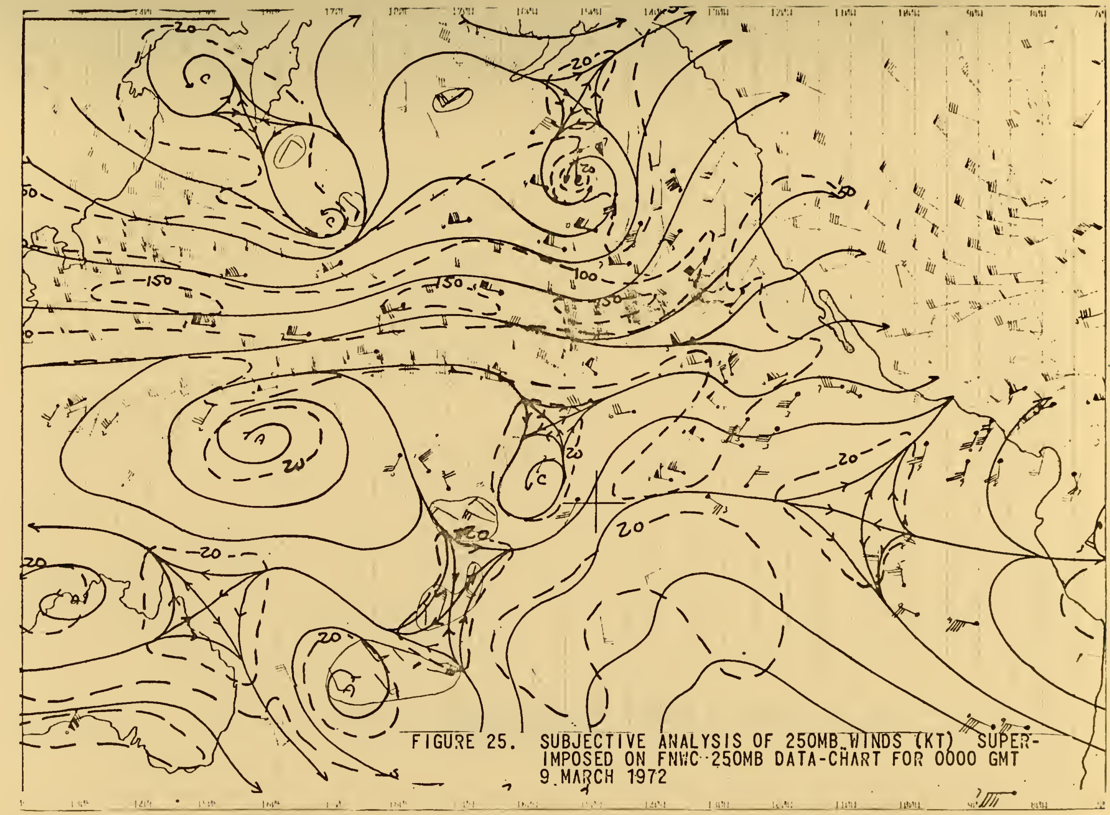

FIGURE 25. SUBJECTIVE ANALYSIS OF 250MB WINDS (KT) SUPERIMPOSED ON FNWC 250MB DATA-CHART FOR 0000 GMT 9 MARCH 1972

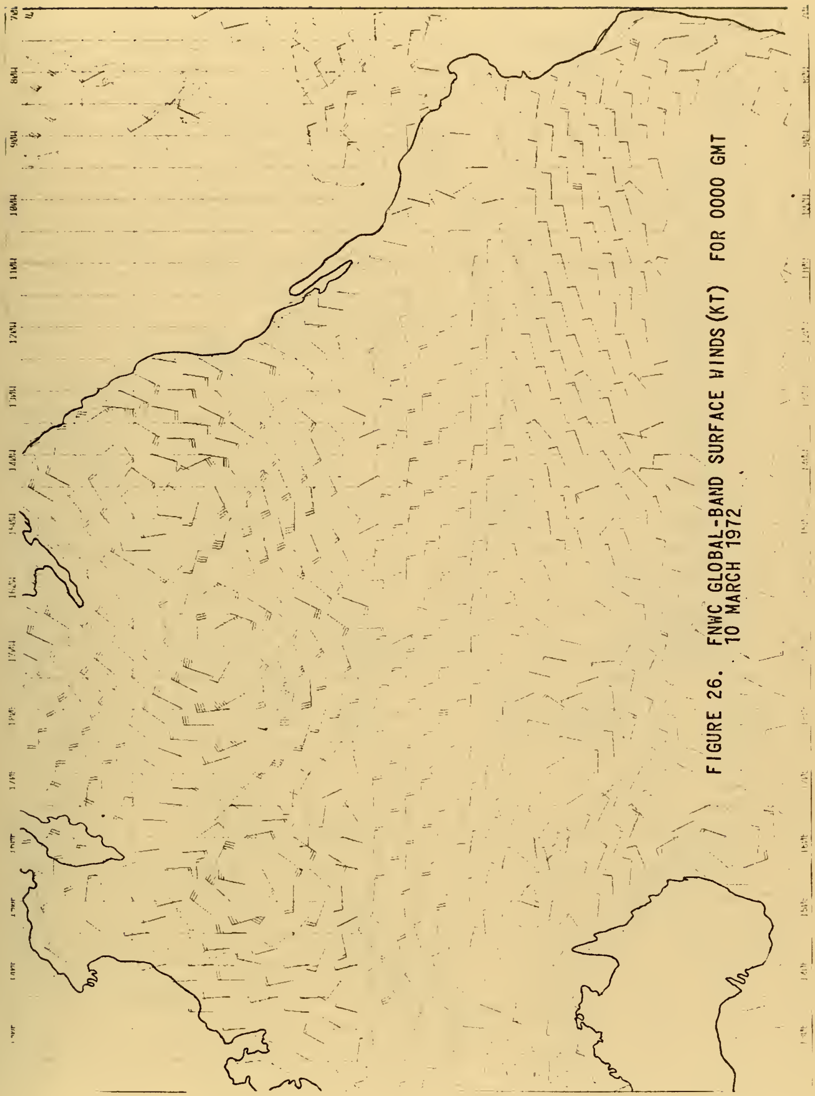

FIGURE 26. FNWC GLOBAL-BAND SURFACE WINDS (KT) FOR 0000 GMT 10 MARCH 1972

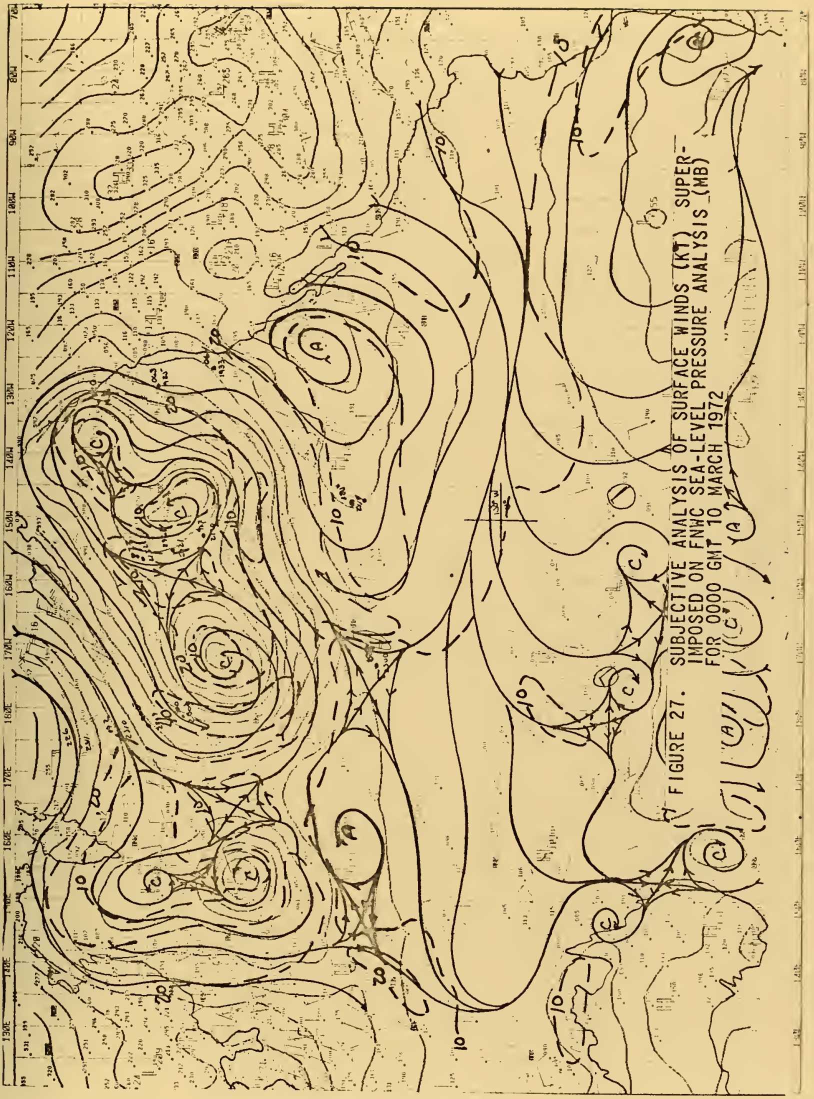

FIGURE 27. SUBJECTIVE ANALYSIS OF SURFACE WINDS (KT) SUPER-IMPOSED ON FNWC SEA-LEVEL PRESSURE ANALYSIS (MB) FOR 0000 GMT 10 MARCH 1972

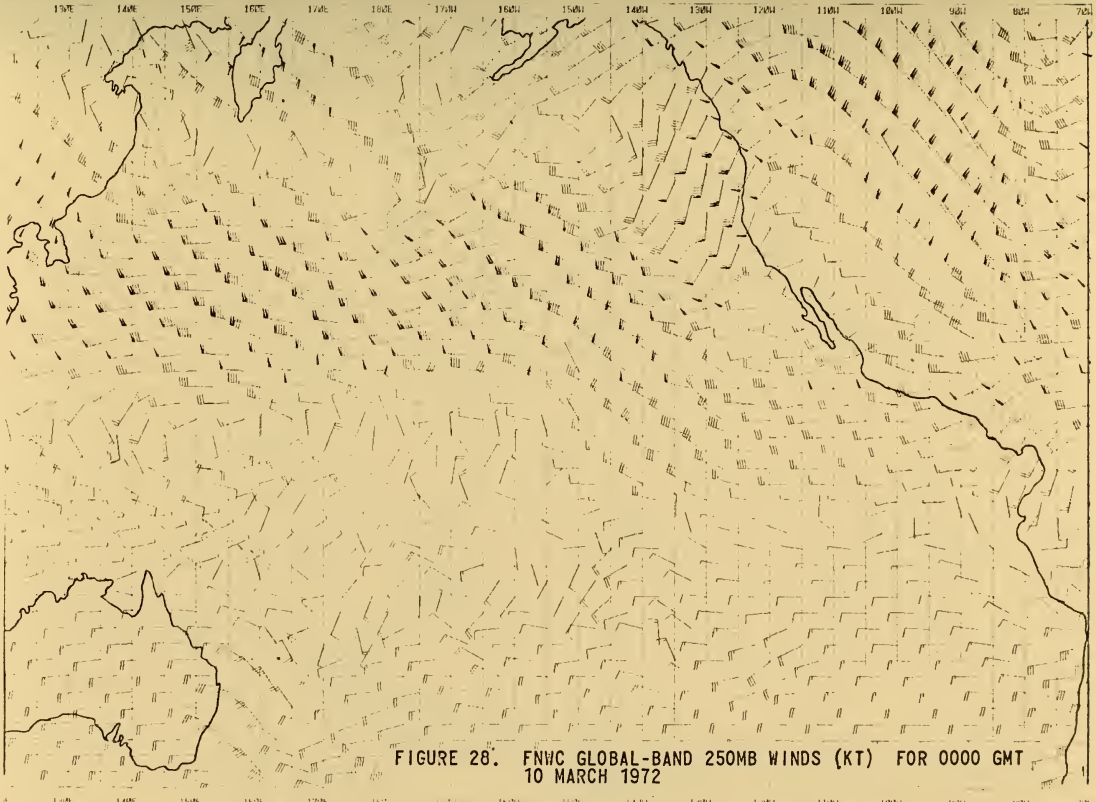

FIGURE 28. FNWC GLOBAL-BAND 250MB WINDS (KT) FOR 0000 GMT
10 MARCH 1972

FIGURE 29. SUBJECTIVE ANALYSIS OF 250MB WINDS (KT) SUPER-IMPOSED ON FNWC 250MB DATA-CHART FOR 0000 GMT 10 MARCH 1972

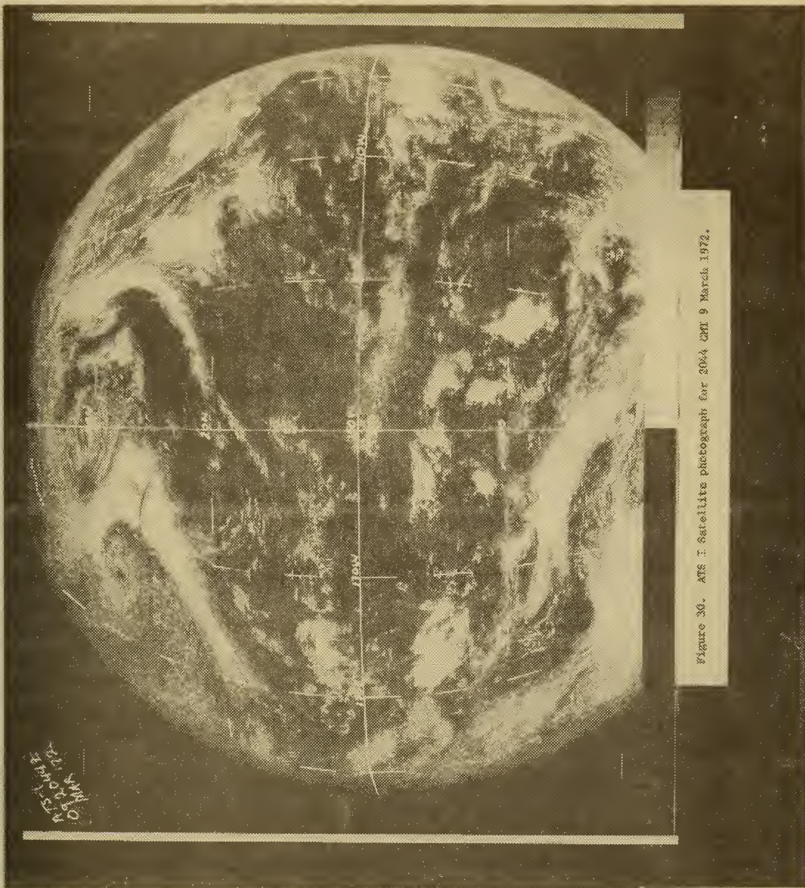

Figure 30. ATS I Satellite photograph for 2044 GMT 9 March 1972.

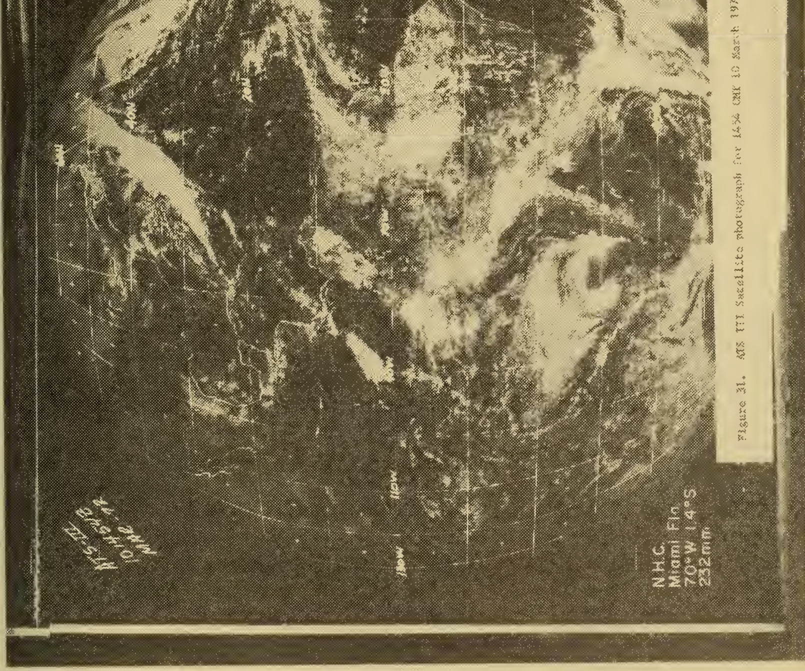

Figure 31. ATS III Satellite photograph for 1454 GMT 10 March 1972.

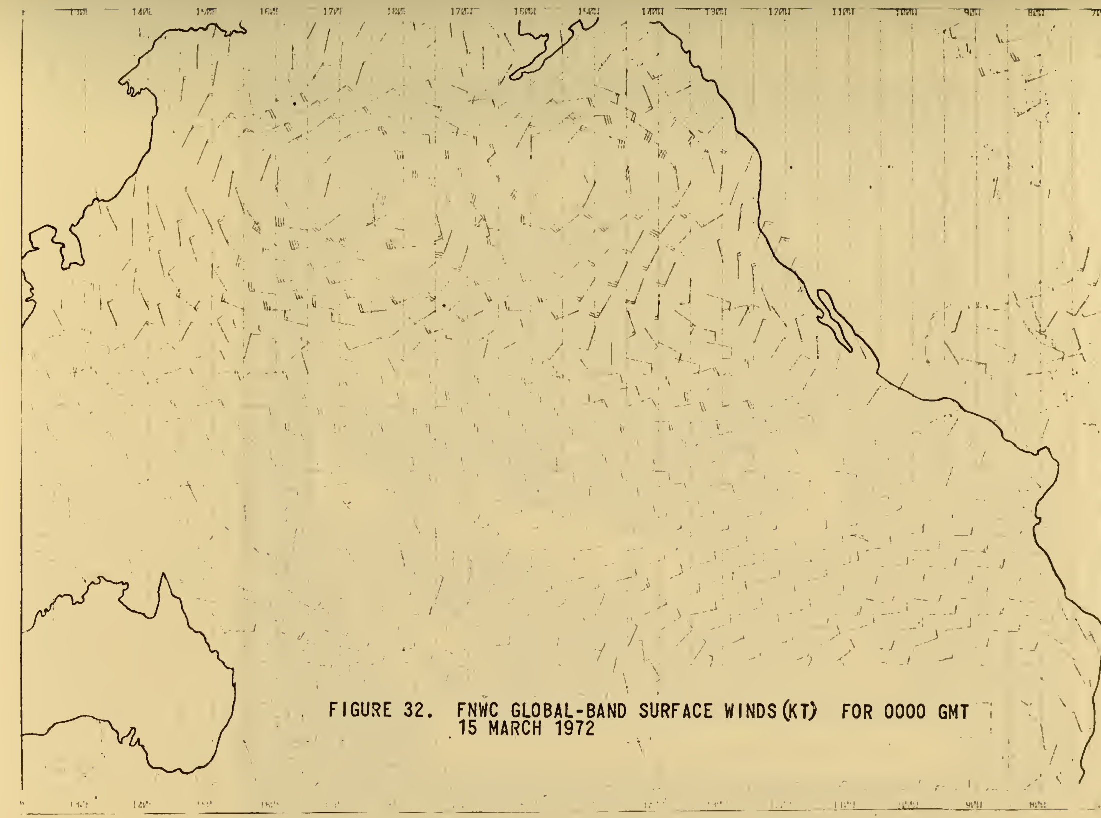

FIGURE 32. FNWC GLOBAL-BAND SURFACE WINDS (KT) FOR 0000 GMT 15 MARCH 1972

Figure 33. ATS I Satellite photograph for 2320 GMT 14 March 1972.

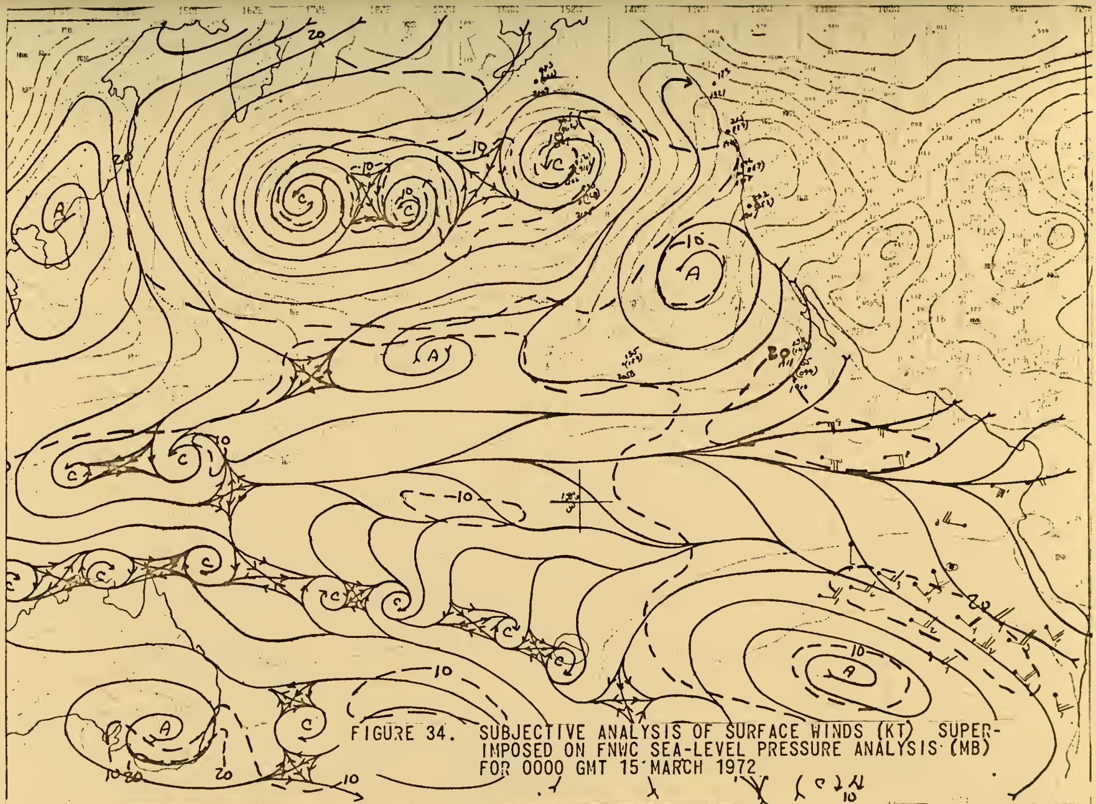

FIGURE 34. SUBJECTIVE ANALYSIS OF SURFACE WINDS (KT) SUPERIMPOSED ON FNWC SEA-LEVEL PRESSURE ANALYSIS (MB) FOR 0000 GMT 15 MARCH 1972

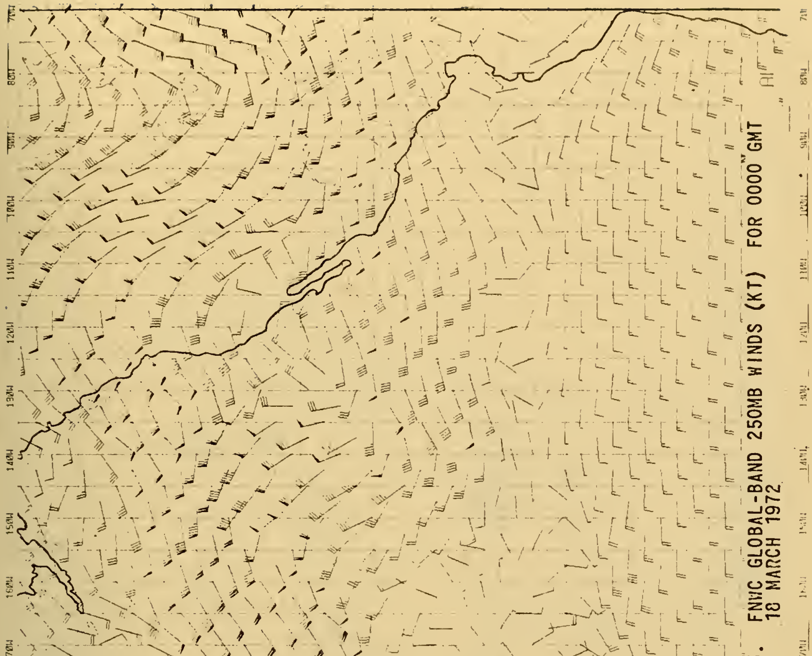

FIGURE 35. FNWC GLOBAL-BAND 250MB WINDS (KT) FOR 0000 GMT
18 MARCH 1972

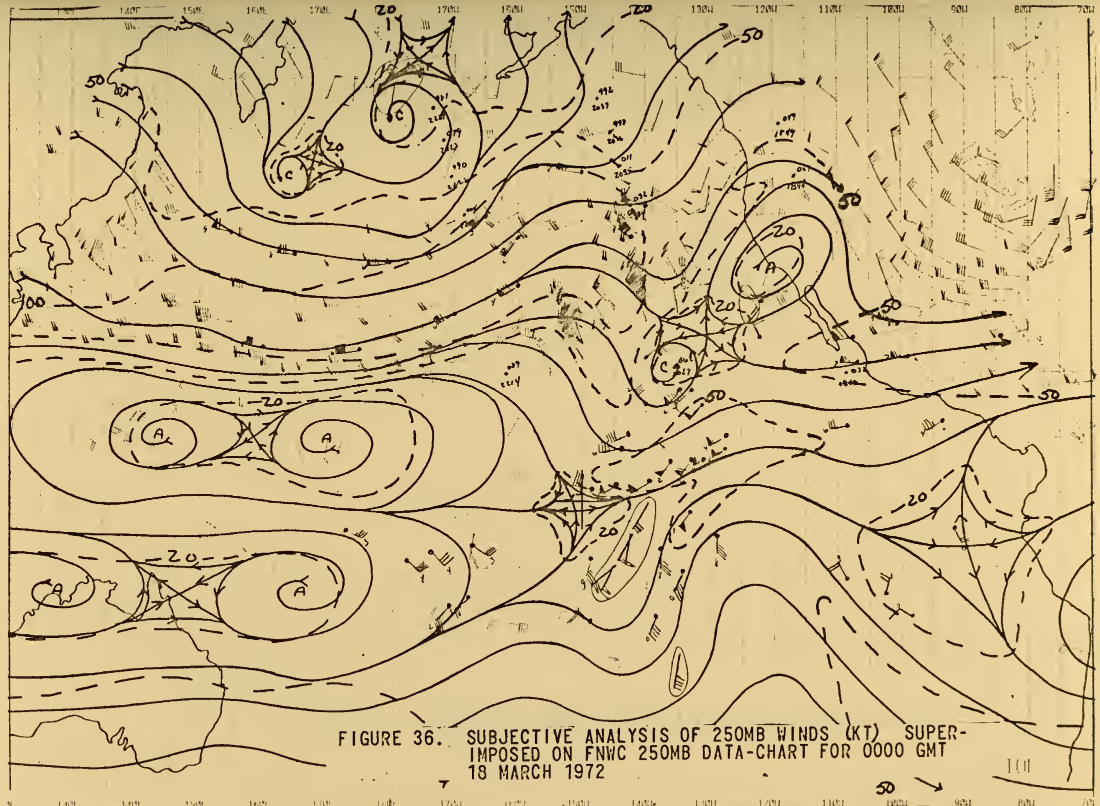

FIGURE 36. SUBJECTIVE ANALYSIS OF 250MB WINDS (KT) SUPER-IMPOSED ON FNWC 250MB DATA-CHART FOR 0000 GMT 18 MARCH 1972

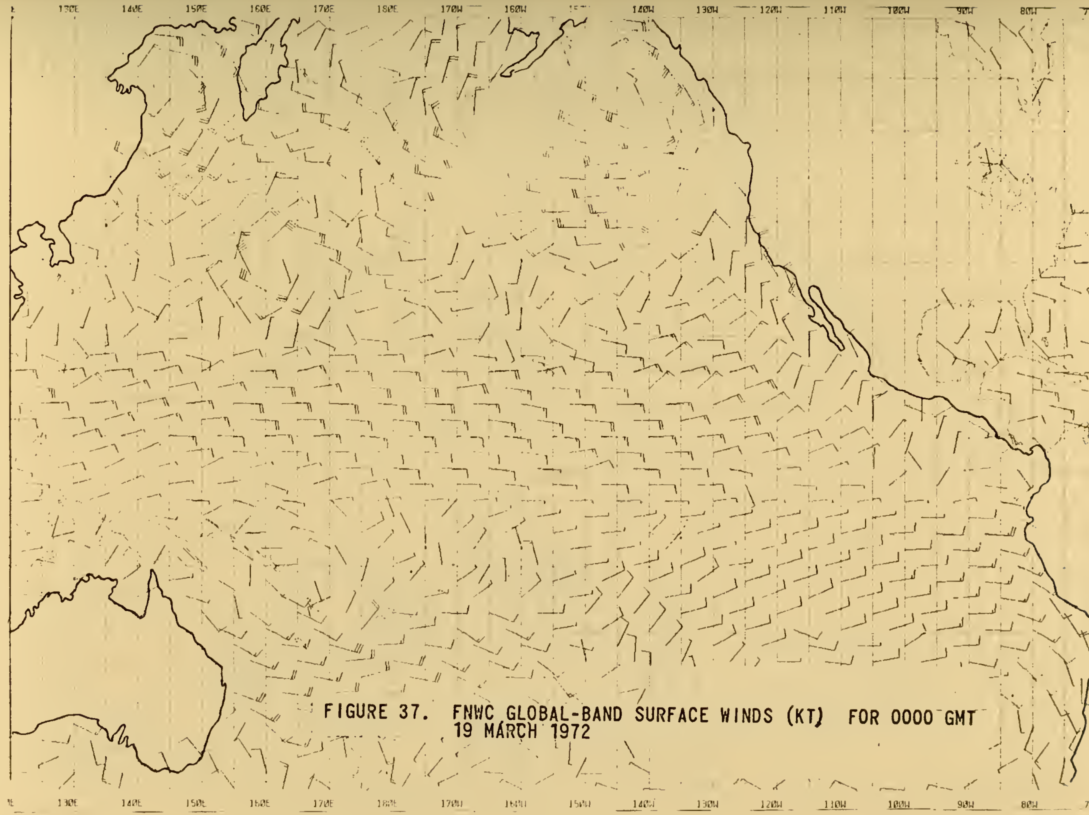

FIGURE 37. FNWC GLOBAL-BAND SURFACE WINDS (KT) FOR 0000 GMT 19 MARCH 1972

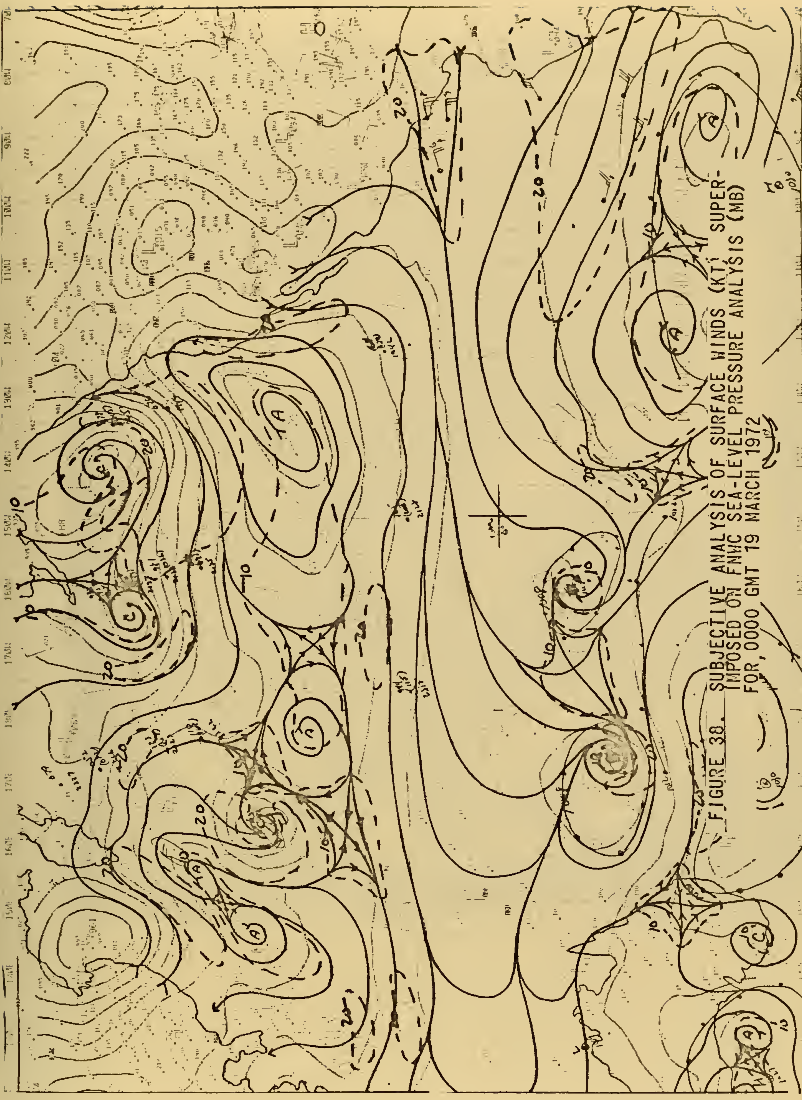

FIGURE 38. SUBJECTIVE ANALYSIS OF SURFACE WINDS (KT) SUPER-IMPOSED ON FNWC SEA-LEVEL PRESSURE ANALYSIS (MB) FOR 0000 GMT 19 MARCH 1972

Figure 39. ATS I Satellite photograph for 2349 GMT 18 March 1972.

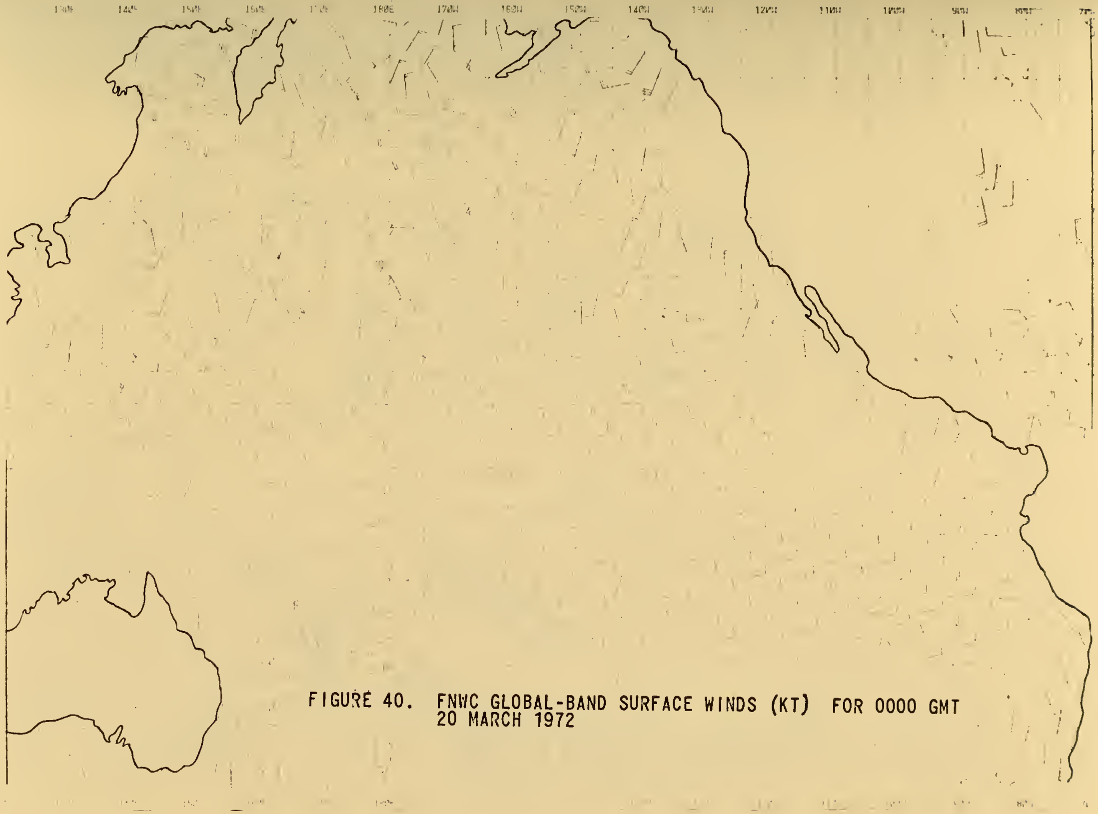

FIGURE 40. FNWC GLOBAL-BAND SURFACE WINDS (KT) FOR 0000 GMT 20 MARCH 1972

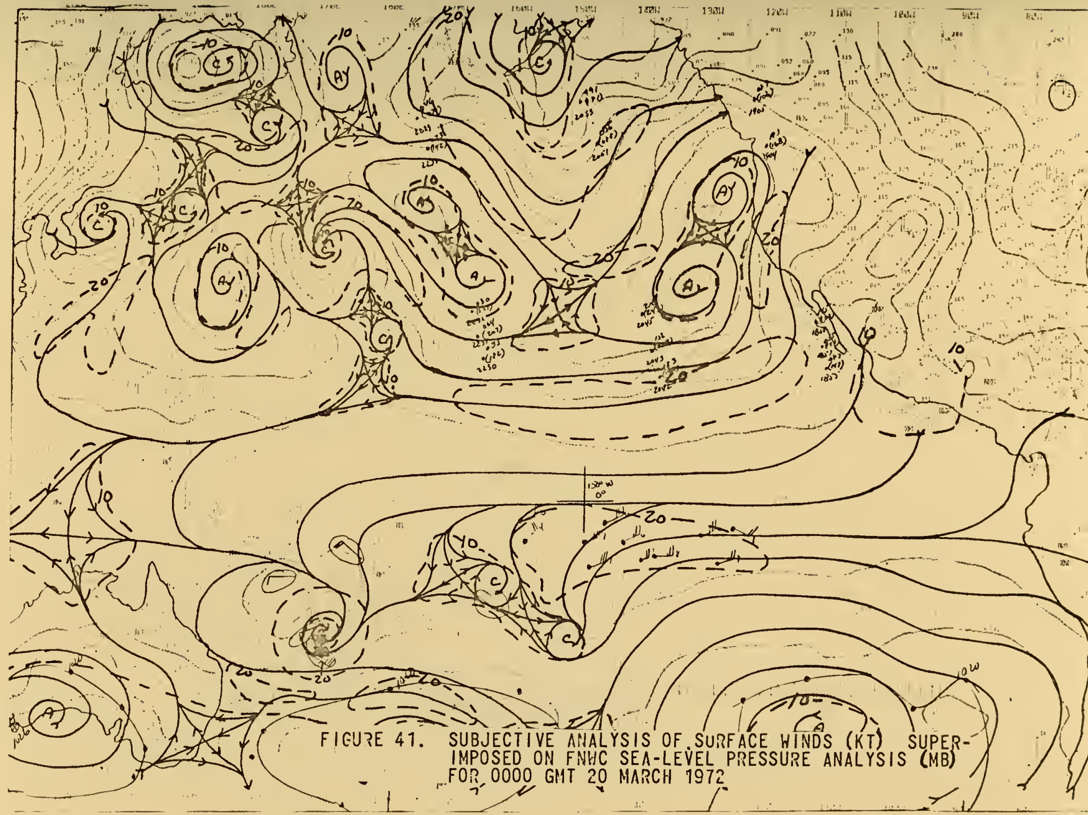

FIGURE 41. SUBJECTIVE ANALYSIS OF SURFACE WINDS (KT) SUPERIMPOSED ON FNWC SEA-LEVEL PRESSURE ANALYSIS (MB) FOR 0000 GMT 20 MARCH 1972

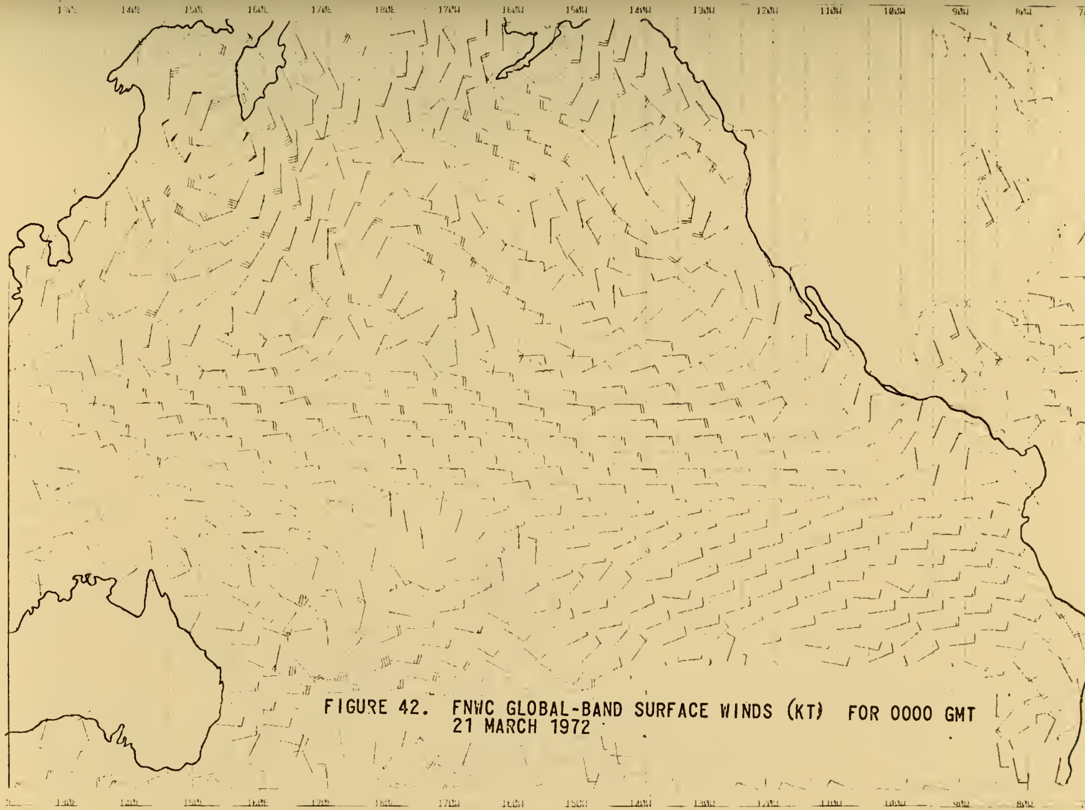

FIGURE 42. FNWC GLOBAL-BAND SURFACE WINDS (KT) FOR 0000 GMT 21 MARCH 1972

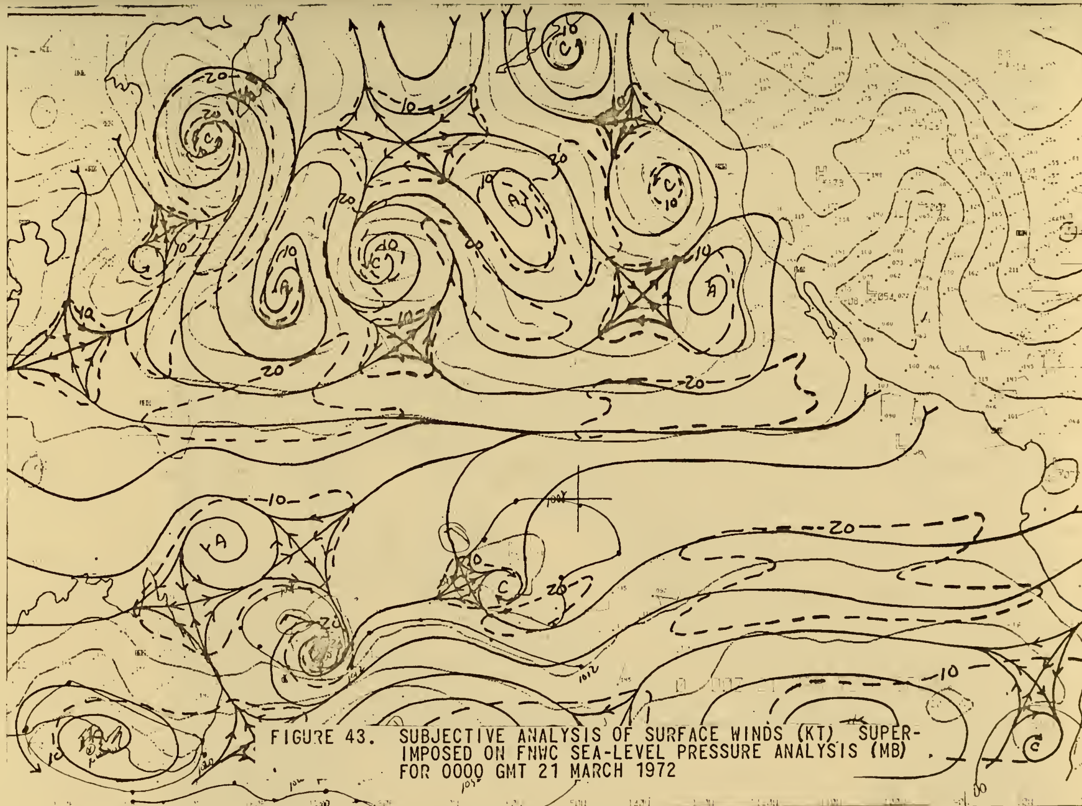

FIGURE 43. SUBJECTIVE ANALYSIS OF SURFACE WINDS (KT) SUPERIMPOSED ON FNWC SEA-LEVEL PRESSURE ANALYSIS (MB) FOR 0000 GMT 21 MARCH 1972

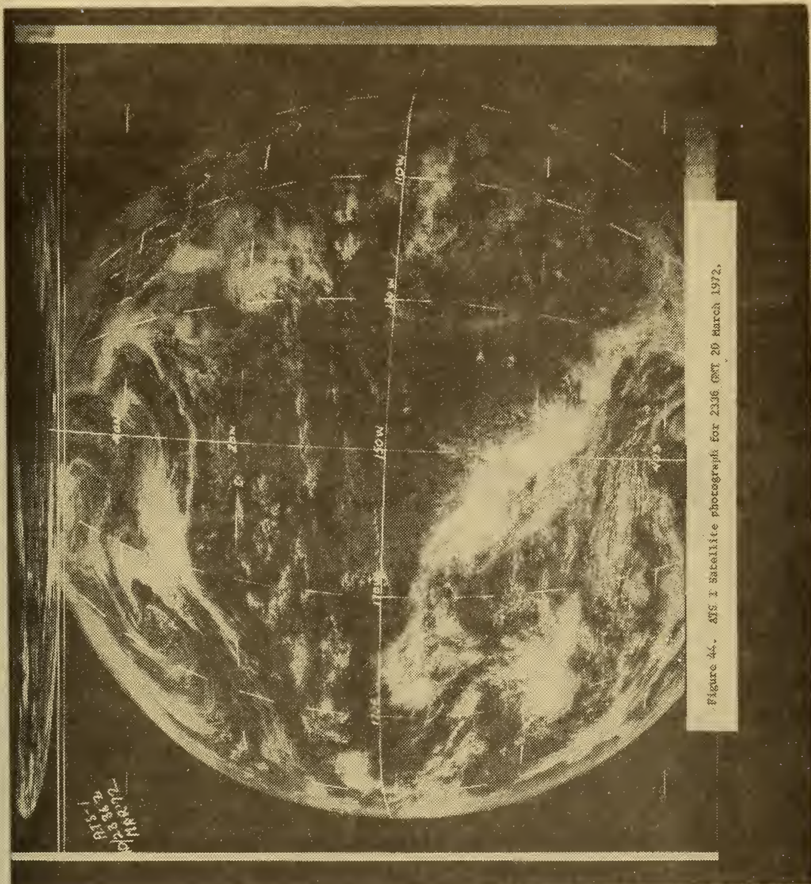

Figure 44. ATS I Satellite photograph for 2336 GMT 20 March 1972.

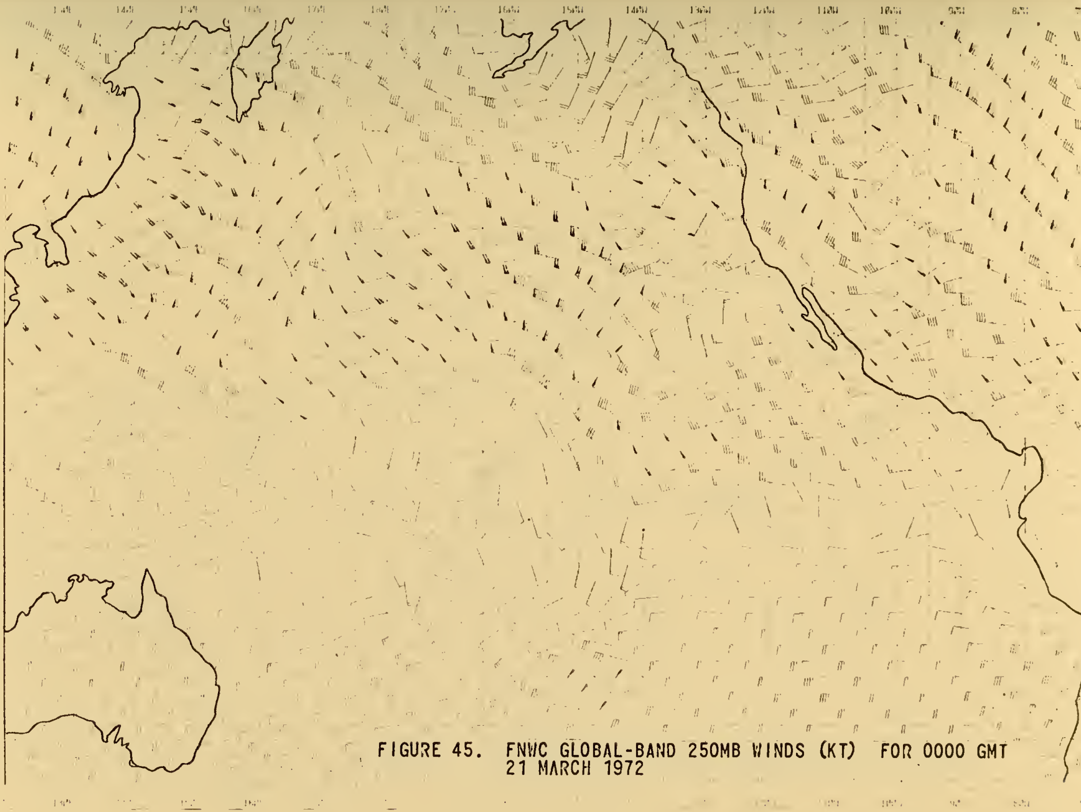

FIGURE 45. FNWC GLOBAL-BAND 250MB WINDS (KT) FOR 0000 GMT
21 MARCH 1972

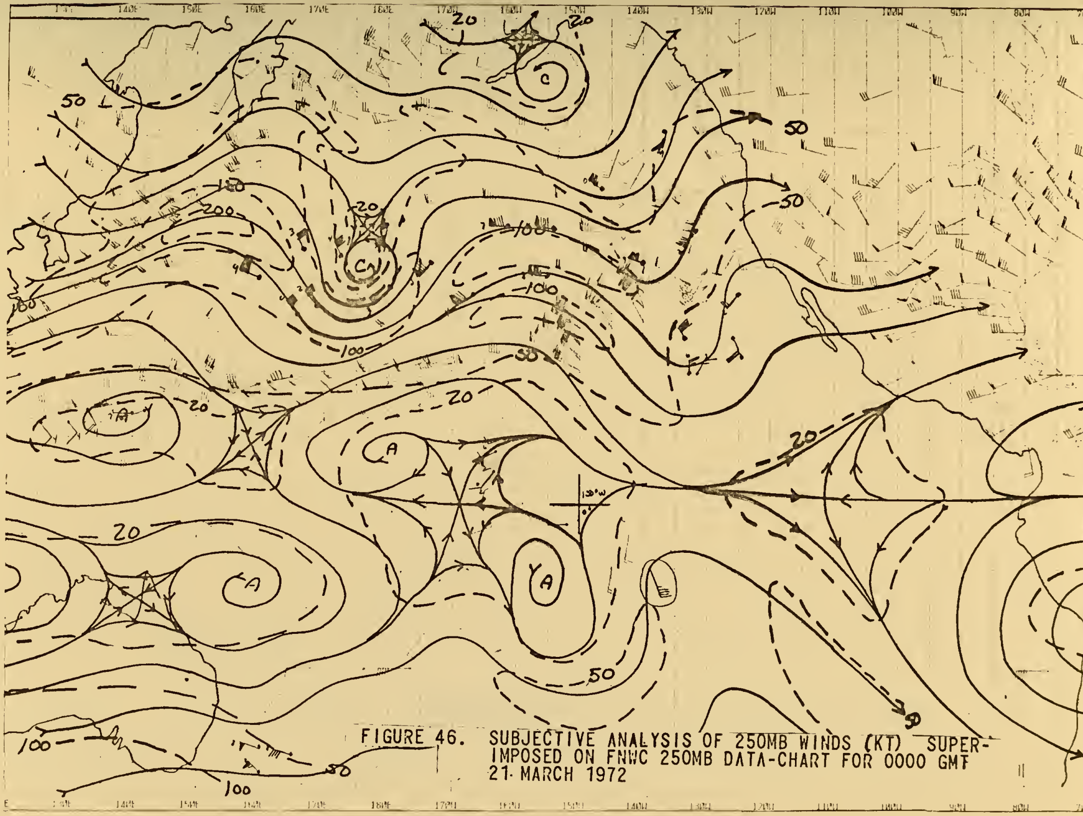

FIGURE 46. SUBJECTIVE ANALYSIS OF 250MB WINDS (KT) SUPERIMPOSED ON FNWC 250MB DATA-CHART FOR 0000 GMT 21 MARCH 1972

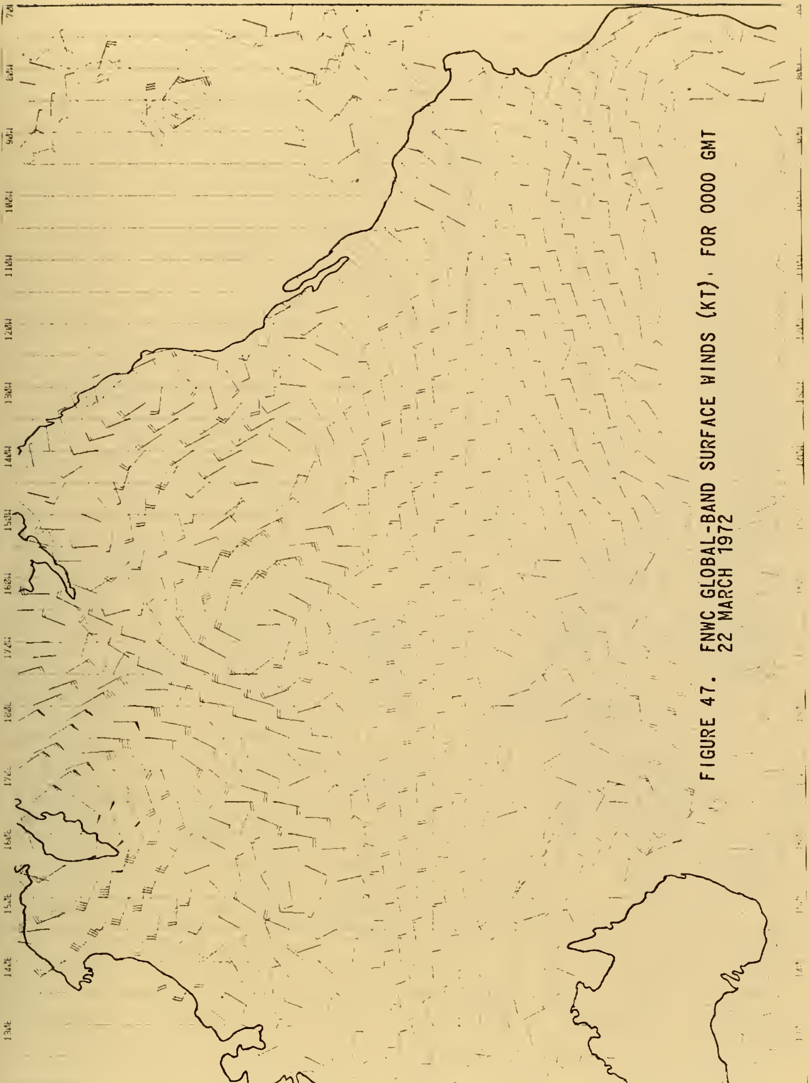

FIGURE 47. FNWC GLOBAL-BAND SURFACE WINDS (KT). FOR 0000 GMT
22 MARCH 1972

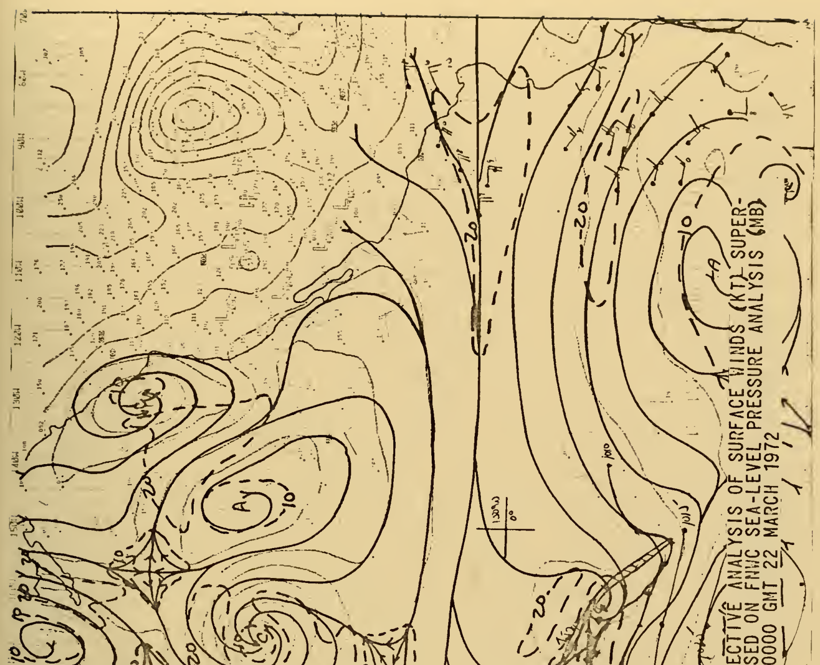

FIGURE 48. SUBJECTIVE ANALYSIS OF SURFACE WINDS (KT) SUPER-IMPOSED ON FNWC SEA-LEVEL PRESSURE ANALYSIS (MB) FOR 0000 GMT 22 MARCH 1972

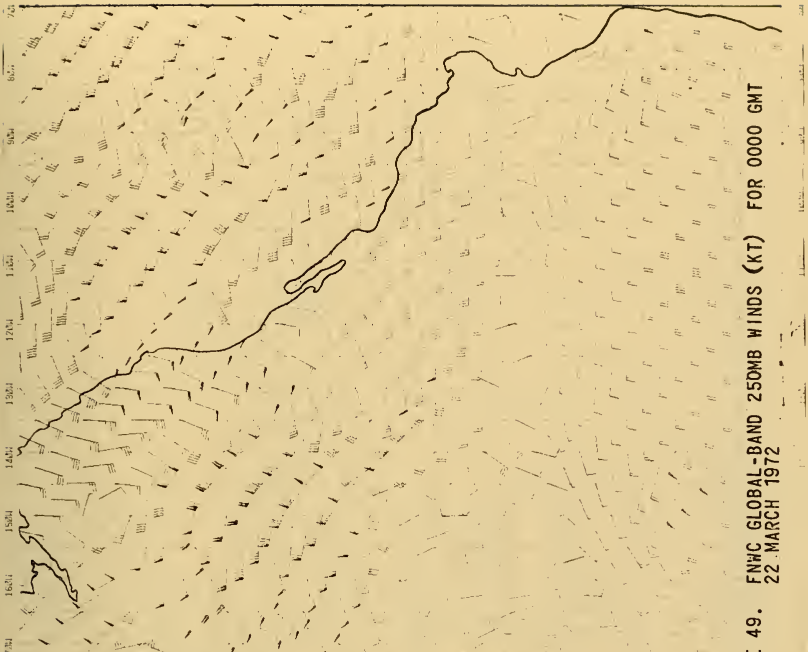

FIGURE 49. FNWC GLOBAL-BAND 250MB WINDS (KT) FOR 0000 GMT
22 MARCH 1972

FIGURE 50. SUBJECTIVE ANALYSIS OF 250MB WINDS (KT) SUPER-IMPOSED ON FNWC 250MB DATA-CHART FOR 0000 GMT 22 MARCH 1972

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13. ABSTRACT

The author presents an evaluative study of Fleet Numerical Weather Central's 0000 GMT surface and 250-mb wind analyses in the Pacific Ocean area 40N to 40S, 120E to North and South America, for the period 8-22 March 1972. The evaluation considers the suitability of the variational analysis scheme and data base by relating numerically- and subjectively-analyzed versions of the two levels for each synoptic time. The report includes an extensive sample of such charts. Several climatologies, including one based on the most recent one or two weeks of analyzed data, were considered along with persistence for the purpose of generating an optimum 24-hour first-guess wind field for analysis or prognosis.

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